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VOL. XVII. ON 1917-18. PART I.

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T ACTIONS

OF

HE CERAMIC SOCIETY

INCLUDING

The Refractory Materials Section.

Founded in 1900 as "The North Staffordshire Ceramic Society," and continued from 1903 to 1916 as "The English Ceramic Society."

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RULES

(Subject to modification by recommendations from the Refractory Materials Section).

1.—The Society shall be called THE CERAMIC SOCIETY. It shall comprise a special section dealing with Refractory Materials.

2.—The object of the Society shall be the discussion of all subjects relating to the industries connected with Clay Working and Refractory Materials.

3.—Persons desirous of membership shall be proposed and seconded by two members of the General Meeting, and they are then eligible for election at the next Council Meeting.

4.—The Society shall be governed by a President, Vice-Presidents, and Committee, a Secretary, and a Treasurer. The officers shall be elected at the last General Meeting of each Session, and hold office until the last General Meeting of the ensuing Session, when they shall be eligible for re-election. Among the Vice-Presidents shall be included all past Presidents who are subscribing members of the Society. A Chairman of Council shall be appointed by the Council. Members of the Council shall be elected to serve 3 years, four members to retire each year, and the retiring members to be eligible for re-election.

5.—The headquarters of the Society shall be the Central School of Science and Technology, Stoke-on-Trent.

6.—The meetings shall be fixed from time to time as arranged by the Sectional Councils. At Stoke-on-Trent the meetings during the Session are usually held at 7 p.m. on the second Saturday of the month.

7.—The annual subscription shall be payable in advance, and shall be fixed from time to time by the Council. Members of the Society who have paid their annual subscription receive a copy of the TRANSACTIONS free.

8.—A firm can join the Society by paying an annual subscription of two guineas. For this subscription the attendance at each meeting shall be limited to three members of the firm, and one copy of the TRANSACTIONS will be supplied free annually.

9.—Notification of meetings shall be sent by post to each member in Great Britain with the name of the subject of the paper for discussion.

10.—In the discussions arising upon any paper, no speaker shall occupy more than ten minutes, or make more than one speech, except by the permission of the Chairman.

11.—Any property of the Society lent to members must be returned within a week.

12.—Any member promising a paper and failing to keep his appointment shall himself provide a substitute.

13.—The Society shall have the prior right of publication of all papers read before it for a period of three months.

14.—Authors must send their papers to the Society before or immediately after the communication has been read. If received in time the paper may be printed in time for the meeting. The official receipt of any paper will be dated from the time it is received by the Secretary.

15.—Members may obtain one copy of each of the back numbers of the TRANSACTIONS at subscription rates, providing they are for their own personal use, and that the number in stock be over 18.

16.—Members who are three years in arrear with their subscriptions shall be informed by means of a printed notice, and if the arrears are not paid within a month their names will be struck off the list *New members are put on the list of members when their subscriptions have been paid.*

17.—A member of the Society may introduce a visitor to an ordinary meeting. A visitors' book is kept to show what non-members are present, and by whom they are introduced. The names of the visitors are read out by the Chairman at the opening of the same meeting.

18.—No alteration or addition to the above Rules shall be made except notice be given in General Meeting, and passed by the ensuing General Meeting. Ten to form a quorum.

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GRIMWADE, C. D., The Watlands, Wolstanton, Stoke-on-Trent (1909-10)
GRIMWADE, L. L., Winton Pottery, Stoke-on-Trent ... ... (1906-07)
GRIMWADE, S. A., The Watlands, Wolstanton, Staffs. ... ... (1911-12)
GRINDLEY, W. H., Woodland Pottery, Tunstall ... ... (1906-07)
HADFIELD, SIR ROBERT, F.R.S.D.Met., D.Sc., 22, Carlton House Terrace, London, S.W. ... ... (1916-17)
HALL, HY., The Bungalow, Botteslow, Hanley ... ... (1912-13)
HALL, J, & Co., Stourbridge ... ... (1916-17)
HALLAM, G. T., 100, Boughey Road, Stoke-on-Trent ... ... (1917-18)
HAMILTON, J., Ideal Pottery, Trenton Potteries Co., Trenton, U.S.A. ... ... (1906-07)
HAMILTON, J. W., c/o R. Muir & Co., Ltd., Armadale Station, Linlithgowshire ... ... (1917-18)
HAMMERSLEY, GODFREY, The Hollies, Leigh ... ... (1913-14)
HAMMOND, PERCY, Newbridge House, Bollington, Macclesfield (1916-17)
HAMMOND, WILLIAM, Jevington, Bollington, Macclesfield ... (1916-17)

HAMPTON, T. E., Eastwood Marl Works, Hanley ... ... (1908-09)
HANCHARD, F., East Gate, Marsh Av., Wolstanton, Stoke-on-Trent (1908-09)
HANCOCK, E. A., Kepax, Worcester ... ... (1916-17)
HANCOCK, F., Ford Street, Shelton, Stoke-on-Trent ... ... (1902-03)
HANCOCK W. C., B.A., F.I.C., 60, Greek Street, Soho Square, London, W. 1 ... ... (1917-18)
HARBORD, F. W., 16, Victoria Street, London, S.W. ... ... (1916-17)
HARRISON, A. C., Bath Street, Hanley ... ... (1910-11)
HARRINGTON, T. H., 55, Stanley Street, Tunstall ... ... (1913-14)
HARTLEY, H. L., Castleford Pottery, Castleford, Yorks.... ... (1917-18)
HAWTHORN, S., Mona House, Congleton, Cheshire ... ... (1905-06)
HAWTHORN, H., Morfa, Woodland Avenue, Wolstanton... ... (1910-11)
HAWLEY, E., Woodland Cottage, Blurton, Staffs. ... ... (1914-15)
HAWLEY, ERNEST, c/o Messrs. Hawley & Jackson, Longton ... (1913-14)
HAWLEY, W. S., Firmont, Sunny Bank Road, Newcastle, Staffs. (1908-09)
*HEATH, A., 61, Bethesda Street, Hanley ... ... (1900-01)
HEATH, C. H., High Street, Woodville, near Burton-on-Trent ... (1915-16)
HEATH, F. H., c/o Redfern & Drakeford, Ltd., Balmoral Works, Normacot ... ... (1914-15)
HEATON, J., Ravenhead, St. Helens ... ... (1916-17)
HEATON, WM., Ravenhead Brick Co., Upholland, near Wigan... (1917-18)
HENDERSON, H. B., 1538, N. High St., Columbus, Ohio, U.S.A. (1911-12)
HENDERSON, J. D., 24, Finsbury Street, London, E.C. ... ... (1917-18)
HEPWORTH IRON Co., Ltd., Hazlehead, near Sheffield... ... (1916-17)
HERLITZ, CARL GUSTY, "Arabia," Helsingford, Finland ... (1912-13)
HEWITT, A. E., Upper Belgrave Road, Normacot, Longton ... (1912-13)
HEWSON, GEO. W., Grasmere, Field Terrace, Jarrow-on-Tyne (1917-18)
HICKMAN, H. T., and N. WOOD, Fireclay Works, Stourbridge (1916-17)
HILL, ALFRED, 9, Cromer Road, Hartshill ... ... (1913-14)
HILL, F. W., c/o Messrs. Burn & Co., Ltd., The Potteries, Raneegunge, India ... ... (1917-18)
HIMLEY FIRE & RED BRICK Co., Ltd., near Dudley ... ... (1916-17)
HOBBS, W. E., Dyserth, Flintshire ... ... (1916-17)
HODSON, G. A., c/o The Hathern Station Brick & Terra-Cotta Co., Ltd., Loughborough ... ... (1908-09)
*HOLDCROFT, A. D., Bradwell Lane, Wolstanton ... ... (1902-03)
*HOLDCROFT, J. P., Bradwell Lane, Wolstanton ... ... (1902-03)
HOLLINSHEAD, J., The Elms, Penkhull, Stoke-on-Trent ... (1905-06)
HOLLINSHEAD, T., 4, The Green, Harpfield, Stoke-on-Trent ... (1906-07)
HOPE, H., c/o Mayer China Co., Beaver Falls, Pa, U.S.A. ... (1907-09)
HORSLEY, G., c/o Messrs. J. Bourne & Son, Denby Pottery, near Derby ... ... (1908-09)
HOWE, J. ALLEN, Museum of Practical Geology, Jermyn Street, London, S.W. ... ... (1916-17)
HOWELL, C. G., 90, Leonard Road, Birches Head, Hanley ... (1916-17)
HOWELL, W. E., 19, Lyndhurst Street, Burslem ... ... (1915-16)
HOWIE, E. C., Fireclay Works, Hurlford, near Kilmarnock, N.B. (1908-09)
HOWIE, F. C., Hurlford Fireclay Works, Kilmarnock ... ... (1916-17)
HOWSON, R. G., c/o Messrs. G. Howson & Sons, Limited, Hanley (1907-08)

HUGHES, F. S., Opal China Works, Fenton, Staffs. ... ... (1909-10)
HURLL, Ltd., P. & M., 144, West Regent Street, Glasgow ... (1917-18)
HUTCHESON, R. E. B., Holloway Villa, Kidwelly, S.W. ... (1916-17)
HUTCHINSON, A., M.A., B.Sc., Manestry, Saltburn-by-the-Sea, Yorks. ... ... (1916-17)
HUTTON, R. S., Dam House, Mushroom Lane, Sheffield... ... (1916-17)
ISIS PORTLAND CEMENT Co., Ltd., Clitheroe, England ... (1916-17)
JACKSON, G. H., Wharf Street, Burslem ... ... (1905-06)
*JACKSON, W., Clough Hall, Kidsgrove ... ... (1900-01)
JENKINSON, W., The Edinburgh & Leith Flint Glass Co., Edinburgh (1916-17)
JEPPSON, G. N., 41, Burncoat Street, Worcester, Mass., U.S.A. (1912-13)
JOHNSON, A. S., c/o Messrs. Alfred Meakin, Ltd., Tunstall ... (1909-10)
JOHNSON, E., c/o Messrs. W. Boulton, Ltd., Navigation Road, Burslem ... ... (1909-10)
JOHNSON, H., Tile Manufacturer, North Rd., Cobridge, Burslem (1906-07)
JOHNSON, J., Talke and Alsager Road, Alsager ... ... (1912-13)
JOHNSON, R. L., Oulton Rocks, Stone, Staffs. ... ... (1912-13)
JOHNSON, W. P., B.Sc., Parkfield, Kingswinford, near Stourbridge ... ... (1910-11)
JOHNSTONE, F. B., c/o Messrs. Pountney & Co., Ltd., Fishponds, Bristol ... ... (1905-06)
JONES, A. B., Grafton Works, Longton ... ... (1914-15)
JONES, A. G., Lynton, Trentham, Staffs. ... ... (1909-10)
JONES, A. G. H., Heath House, Uttoxeter ... ... (1905-06)
JONES, CHARLES, Heatherfield, Bwlchgwyn, near Wrexham ... (1916-17)
JONES, E. A., 20, Church Terrace, Blythe Bridge ... ... (1903-04)
JONES, E. G., 714, Oakhill, Stoke-on-Trent ... ... (1910-11)
JONES, E. O., Fairmont, Queen's Road, Hartshill, Stoke-on-Trent (1913-14)
JONES, F., 96, Cromartie Street, Longton ... ... (1908-09)
JONES, GREVILLE, Clarence Iron & Steel Works, Port Clarence, Middlesbro' ... ... (1916-17)
JONES, L., Southwood, c/o Messrs. Southwood, Jones & Co., Risca, Monmouth ... ... (1916-17)
JONES, N. L., c/o J. & G. Meakin, Ltd., Hanley ... ... (1914-15)
*JONES, R. H. H., Riversdale, Keyberry Road, Newton Abbot ... (1900-01)
JONES, W. J., Palace Chambers, Westminster, S.W. ... ... (1916-17)
KEELING, F. A., c/o Messrs. Keeling & Walker, Stoke-on-Trent (1906-07)
KEELING, J., c/o Keeling & Co., Dalehall, Burslem ... ... (1906-07)
KENT, W. F., 72, Leonard Street, Burslem ... ... (1903-04)
KIRKLAND, H. S., Albion Pottery, Etruria, Stoke-on-Trent ... (1906-07)
KLEIN, CARL A., 4, Brimsdown Av., Enfield Highway, Middlesex (1915-16)
KNIGHT, W. C., 29, Rushton Road, Cobridge, Burslem ... ... (1908-09)
KNIGHT, W. H., Pearl Brook Works, Horwich, Lancashire ... (1916-17)
LANCASTER, E., Lyndhurst, Trentham ... ... (1914-15)
LEACH, C. A., Padeswood, Weston Coyney, Stoke-on-Trent ... (1912-13)
LEATHER, J. P., Gas Works, Burnley ... ... (1916-17)
LEEDS FIRECLAY Co., Ltd., Wortley, Leeds ... ... (1916-17)
*LEESE, A., 81, Vivian Road, Fenton, Staffs. ... ... (1900-01)
LEIGH, A. K., Oulton Cross, Stone, Staffs. ... ... (1914-15)
LEIGH, A. R., Ambleside, Midway, Burton-on-Trent ... ... (1909-10)

LESSING, R., Ph.D., The Laboratory, Southampton House, 317, High Holborn, London ... ... (1910-11)
LESTER, F. G., Field Place, Walton, Stone, Staffs. ... ... (1908-09)
LESTER, G., 152, Ashford Street, Shelton, Stoke-on-Trent ... (1916-17)
LILLESHALL (The) Co., Ltd., Priors Lee Hall, Shifnal, Salop... (1916-17)
LILLIBRIDGE, H. D., c/o American Encaustic Tiling Co., Ltd., Zanesville, Ohio, U.S.A. ... ... (1916-17)
LINDOP, R. C., 41, Grove Road, Fenton ... ... (1913-14)
LINSTRUM, T., 2, Oakwood Drive, Roundhay, Leeds ... ... (1917-18)
LLOYD, HORACE, Messrs. N. B. Allen & Co., Ltd., Hirwain, South Wales ... ... (1917-18)
LLOYD, W. J., Rothesay, King's Avenue, Wolstanton ... ... (1915-16)
LOUDON, JOHN, Loudon & Russell, Ltd., Allanton Fireclay Works, Newmains, Scotland ... ... (1917-18)
LOVATT, L. D., 79, Festing Street, Hanley ... ... (1916-17)
MACFARLANE, A. & P., 121, St. Vincent Street, Glasgow ... (1917-18)
MACHIN, C. W., Parkfield, Longton ... ... (1914-15)
MACLAY, DAVID M., Dalzell Steel and Iron Works, Motherwell... (1917-18)
MacNEAL, C., Highfield House, Fenton, Staffs. ... ... (1910-11)
MacWHIRTER, J., Elisnore, Milngarvie, Scotland ... ... (1917-18)
McDONALD, J. A. K., 24, Chapel Street, Liverpool ... ... (1916-17)
MALINOVSZKY, A., 22 N. Douglas Avenue, Belleville, Ill., U.S.A ... ... (1916-17)
MALKIN, S., c/o The Malkin Tile Works Co., Burslem ... ... (1905-06)
MALKIN, W. F., Dalehall Mill, Burslem ... ... (1914-15)
MARLOW, J. H., 19, Villas, Stoke-on-Trent ... ... (1916-17)
MARSHALL, F. G., 56, Berwick Road, Gateshead ... ... (1911-12)
MASON, ADAM, & SONS, Ltd., Horwich, Lancashire ... ... (1916-17)
MASON, J. C., 16, Moor Street, Brierley Hill, Staffs. ... ... (1916-17)
MAYER, E., Beaver Falls, Pa, U.S.A. ... ... (1904-05)
*MAYER, E. W. T., 11, Westwood Road, Wolstanton ... ... (1914-15)
MEADE, ALWYNE, Commercial Gas Co., Wapping, London, E. 1 (1916-17)
MEIR, J., 240, Waterloo Road, Burslem ... ... (1911-12)
MELLOR, J. R., Eversley Villa, Ricardo St., Dresden, Longton... (1910-11)
*MELLOR, J. W., D.Sc., Sandon House, Regent St., Stoke-on-Trent (1904-05)
MEREDITH, J., Hamworthy Villa, Poole, Dorset ... ... (1911-12)
MICHIE, A. C., 82, Collingwood Building, Newcastle-on-Tyne ... (1910-11)
MIDDLETON FIRECLAY WORKS, Leeds ... ... (1916-17)
MITCHELL, JOHN, 142, Queen Street, Glasgow ... ... (1916-17)
MITCHELL. J. S., Hyland, Hargate Drive, Hale, Manchester ... (1917-18)
*MOORE, B., Draycott, Blythe Bridge, Stoke-on-Trent ... ... (1900-01)
MOORE, BERNARD J., The Grange, Draycott, Stoke-on-Trent... (1913-14)
MOORE, HOWARD, Harper & Moores, Ltd., Stourbridge ... (1916-17)
MOLE, J., 28, Saltbrook Road, Lye ... ... (1916-17)
MOMOKI, S., 33, Kobayashi-Cho, Nagoya, Japan ... ... (1916-17)
MORRALL, F., 49, Kensington Road, Oakhill, Stoke-on-Trent ... (1917-18)
MOTTRAM, GEO. WM., Mill Street Siding Goods Yard, Hanley (1916-17)
MOUNTFORD, E. J., 14, Leek Road, Smallthorne, Staffs. ... (1913-14)
MUTCHS, STANLEY, R., Camerton Coal, Firebrick & Ganister Co., Camerton, Workington, Cumberland ... ... (1916-17)

MYOTT, A., c/o Messrs. Myott, Son & Co., Cobridge, Burslem ... (1904-05)
NIXON, WM., Mayfield, Weston Coyney, Stoke-on-Trent ... (1916-17)
NEWMAN, H. S., Sunnyside, Oxford Road, Basford Park, Stoke-on-Trent ... ... (1917-18)
OAKES, E. J., Sunny Bank, High Lane, Burslem ... ... (1914-15)
OATES & GREEN, Ltd., Halifax, Yorks. ... ... (1916-17)
*ODELBERG, A. S. W., Gustafsberg Pottery, Sweden ... ... (1904-05)
O'KURA, K., 33, Kobayashi-Cho, Nagoya, Japan ... ... (1915-16)
*OLSEN, B., c/o Messrs. Harrison & Son, Ltd., Bath St., Hanley (1900-01)
ORTON, E., Columbus, Ohio, U.S.A. ... ... (1903-04)
*PAGE, E. P., 123, Abbey Foregate, Shrewsbury ... ... (1904-05)
PAINE, W. H. C., Calder Fireclay Co., Coatbridge ... ... (1916-17)
PARKINSON & SPENCE, Ambles Thorn Fireclay Works, Halifax (1916-17)
PARMELEE, C. W., Professor of Ceramic Engineers, University of Illinois, Urbana, Illinois, U.S.A. ... ... (1906-07)
PARRY, ROBT., Oak Bank, Rhos, near Wrexham ... ... (1916-17)
PEARSALL, W. H., c/o Mobberley & Bayley, Stourbridge... ... (1916-17)
PEARSON, E. J. & J., Ltd., Fireclay Works, Stourbridge ... (1916-17)
PERRY, PEARSON, G. H. Stourbridge ... ... (1916-17)
*PERRY, T., 55, Stanfield Road, Burslem ... ... (1910-11)
PHILLIPS, ROBT. W., Plas Madoc Cottage, Ruabon ... ... (1917-18)
PICKFORD, HOLLAND & Co., Ltd., Eclipse Ganister Works, Sheffield ... ... (1916-17)
PICKFORD, R. J., Thornlea, Carmel Road, Darlington ... ... (1917-18)
PIKE, L. G., Wareham, Dorset ... ... (1912-13)
PINKERTON, D. J., Dalzell Steel & Iron Works, Motherwell ... (1916-17)
PITCAIRN, G., Fabrica-de-Loza, San Juan de Aznal-farache, Sivilla, Spain ... ... (1916-17)
PITTAR, T. F. ... ... (1910-11)
PLANT., F., Stone Road, Longton ... ... (1912-13)
*PLANT, H. J., Meadowcroft, Blythe Bridge, Stoke-on-Trent ... (1902-03)
PLANT, J., Melbourne House, Stone ... ... (1912-13)
PODMORE, A. J., Tunstall Art Pottery, High Street, Tunstall ... (1916-17)
PODMORE, WM., Brooklands, Goldenhill, Stoke-on-Trent ... (1913-14)
POOLE, THOS., Cobden Works, Longton ... ... (1915-16)
POOLE, HORACE, 96, Chaplin Road, Longton ... ... (1916-17)
POWELL, W. H., 1170, Broadway, New York City, U.S.A. ... (1908-09)
PRESTON, D., 35, High Street, Bucknall, Stoke-on-Trent ... (1916-17)
PRICE, G., Clifton, Silverdale Road, Wolstanton, Staffs.... ... (1908-09)
PRICE, J. T. & Co., Ltd., Stourbridge ... ... (1916-17)
PRICE, S. H., St. George's, Porthill, Longport, Stoke-on-Trent... (1912-13)
PRICE, J. H., 39, St. Thomas Street, Bristol... ... ... (1917-18)
PURDY, R. C., Norton Co., Worcester, Mass., U.S.A. ... ... (1905-06)
PYKE, IVAN S., Oketon, Oxford Street, Castleford, Yorks. ... (1911-12)
*RAMSDEN, C. E., The Knoll, Basford, Stoke-on-Trent ... ... (1902-03)
RAMSEY, A., Mount Savage, Md., U.S.A. ... ... (1908-09)
RAWDON SMITH, F., Eastfield, Ironbridge, R.S.O., Salop ... (1902-03)
REES, WALTER, J., Department of Refractory Materials, The University, Sheffield ... ... (1916-17)
REYNOLDS, G., Tachbroke House, Normacot ... ... (1903-04)

*RICHARDSON, A. G., "Linden," Oakville Avenue, High Lane, Burslem ... ... (1900-01)
RICHARDSON, GEO., 140, Pinnox Street, Tunstall ... ... (1913-14)
RICHARDSON, W. D., The Claycroft Mining and Brick Co., Shawnee, Ohio, U.S.A. ... ... (1906-07)
RIDGE, H. M., 2, Great Winchester Street, E.C. 2 ... ... (1917-18)
RIDGWAY, B., Bedford Works, Hanley ... ... (1913-14)
RIES, H., Cornell University, Ithaca, New York ... ... (1911-12)
ROBERTS, J. G., c/o Messrs. Shanks & Co., Barrhead, N.B. ... (1904-05)
ROBINSON, H. M., c/o Messrs. Minton & Co., Ltd., Stoke-on-Trent (1909-10)
RUSSELL, FRANK, Highland Grove, Worksop ... ... (1916-17)
RYLES, A. H., Bleak Street, Burslem ... ... (1905-06)
SANDLAND, T. H., 76, Newcastle Road, Stone, Staffs. ... ... (1917-18)
SANITER, E. H., Phœnix Special Steel Works, The Ickles, Sheffield (1916-17)
SANKEY, C. H., Wildcroft, Chislehurst, Kent ... ... (1916-17)
SAYER, JAMES, Junr., Hill Crest, James St., Stoke-upon-Trent (1912-13)
SCRIVENER, E. D., c/o Messrs. Taylor, Tunnicliff & Co., Eastwood, Hanley ... ... (1908-09)
SCOTT, Dr. A., The University, Glasgow ... ... (1917-18)
*SEARLE, A. B., The White Building, Sheffield ... ... (1907-08)
*SHAH, C. P., c/o Twyfords, Ltd., Etruria ... ... (1913-14)
SHANKS, D., Arthurlie, Barrhead, N.B. ... ... (1905-06)
SHEARER, A. J., c/o Messrs. Harper & Moores, Ltd., Stourbridge (1916-17)
SHEGOG, T. A., 462, Rutherford Avenue, Trenton, N.J., U.S.A. (1907-08)
SHELLEY, P., c/o Messrs. Wileman & Co., Foley China Works, Longton ... ... (1905-06)
SHENTON, R., c/o Messrs. Wedgwood & Co., Tunstall ... ... (1903-04)
SHERLOCK, A., Winterton Pottery, High Street, Longton ... (1916-17)
SHORTER, C. A., Friarswood, Newcastle, Staffs. ... ... (1906-07)
SHORTER, J. G., Chetwynd House, Wolstanton, Stoke-on-Trent (1909-10)
SIMPSON, T. A., Lyndhurst, Wolstanton ... ... (1914-15)
SIMPSON, W. A., 27, Kensington Road, Oakhill, Stoke-on-Trent (1916-17)
SIMPSON, T. G., 34, Elm Street, Cobridge, Stoke-on-Trent ... (1917-18)
SITCH, CHARLES HENRY, Workers' Institute, Cradley Heath, Staffs. ... ... (1916-17)
SMART, H. E., Mountain View, Kidwelly, Carmarthenshire ... (1916-17)
SMITH, H. PROCTER, Hawarden Bridge Steel Works, Shotton, Chester ... ... (1916-17)
SMITH, OLIVER, Belle Vue Terrace, Hunwick, Willington, S.O., Co. Durham ... ... (1916-17)
SNEYD COLLIERIES, Ltd., Burslem ... ... (1916-17)
SOLON, L. V., c/o American Encaustic Tile Co., Ltd., 16, East 40th Street, New York, U.S.A. ... ... (1915-16)
SOMERVILLE, W., The Cottage, Hindlow, Buxton ... ... (1916-17)
SOUTH METROPOLITAN GAS Co., 709, Old Kent Road, London S.E. 15 ... ... (1917-18)
SPEIRS, C. W., The Morgan Crucible Co., Battersea Works, London ... ... (1916-17)
*STANLEY, WALTON, Trinity Street, Hanley ... ... (1911-12)
STANYER, A., 109, Sneyd Hill, Burslem ... ... (1903-04)

STEAD, J. E., 11, Queen's Terrace, Middlesbro' ... ... (1916-17)
STEELE, H. L., 15, Regent Road, Hanley ... ... (1912-13)
STEIN, JOHN G. & Co., Ltd., Bonnybridge, Scotland ... ... (1916-17)
STEPHENS, ALFRED, Broomhill, Kidwelly... ... ... (1916-17)
STEVENSON, H. W., Montrose, 1st Avenue, Porthill ... ... (1913-14)
STIFF, S. J., c/o Messrs. B. Fayle & Co., Ltd., Corfe Castle, Dorset ... ... (1913-14)
STOURBRIDGE REFRACTORIES Co., Ltd., Pensnett, nr. Dudley (1916-17)
STOVER, E., 474, West State Street, Trenton, U.S.A. ... ... (1903-04)
STRINGER, G. E., The Villas, Stoke-on-Trent ... ... (1905-06)
STEIGER. EUGENE, "Sunnymead," Fordington Road, Highgate, London, N. ... ... (1916-17)
SWINDEN, THOMAS, 12, Nether Edge Road, Sheffield ... ... (1916-17)
TAMS, H., Wharf Street, Longton, Stoke-on-Trent ... ... (1913-14)
TAYLOR, F. E., Trentham, Staffs. ... ... (1913-14)
TAYLOR, J. F., Trentham, Staffs ... ... (1915-16)
TAYLOR, M., Highfield, Kilmarnock, N.B. ... ... (1908-09)
TAYLOR, T., Rosendale, Newcastle, Staffs. ... ... (1909-10)
TAYLOR, T. M., Shanklin, Weston Road, Meir ... ... (1908-09)
THOMAS, C. W., c/o Messrs. E. J. & J. Pearson, Ltd., Brierley Hill, S. Staffs. ... ... (1903-04)
*THOMASON, W., Royal Doulton Potteries, Lambeth, London, S.E. (1909-10)
THORLEY, P. S., Froghall Lime Works, Cheadle, Staffs. ... (1907-08)
TILL, H. H., 28, West Parade, Mount Pleasant, Fenton ... ... (1911-12)
*TIMMIS, G. H., Pedmore, Stourbridge ... ... (1916-17)
TOOTH, W. E., Claridge House, Woodville, Burton-on-Trent ... (1913-14)
*TOWNSEND, H., Mount Avenue, Hartshill, Stoke-on-Trent ... (1909-10)
TRAVIS, W. P., Church Street Chambers, Stourbridge ... ... (1916-17)
TRIVETT, W. O., Dudley House, 36 and 38, Southampton Street, Strand, W.C. 2 ... ... (1914-15)
*TURNER, F., 2, York Street, Burslem ... ... (1900-01)
TURNER, W. E. S., D.Sc., Department of Glass Technology, The University, Sheffield ... ... (1916-17)
TWYFORD, T. W., Whitmore Hall, Newcastle, Staffs. ... ... (1907-08)
UNITED COLLIERIES, Ltd., 109, Hope Street, Glasgow ... (1916-17)
UNITED ALKALI Co., Cunard Building, Liverpool ... ... (1917-18)
UNWIN, A. J. ... ... (1912-13)
VAUGHAN, A. J., Grant Street Colour Works, Burslem ... ... (1914-15)
WADE, G., High Street, Burslem ... ... (1914-15)
WALKER, E. E., The Australian Tesselated Tile Co., Ltd., Mitcham, Victoria, Australia ... ... (1916-17)
WALKER, F. W., Art Tile Works, Beaver Falls, Pa, U.S.A. ... (1906-07)
WALKER, JOHN, The Gate Farm Fireclay & Firebrick Works, Kingswinford, near Dudley ... ... (1916-17)
WALMSLEY, J. H., "Inauda," Solihull, Birmingham ... ... (1902-03)
WALTON, C. J., Forsbrook, Stoke-on-Trent ... ... (1912-13)
WARBURTON, T. H., The Monk Bridge Iron & Steel Co., Ltd., Leeds ... ... (1916-17)
WATERHOUSE, JAMES, Ltd., Soho Works, Wakefield ... ... (1916-17)
WATKIN, E., 57, Yoxall Avenue, Hartshill ... ... (1916-17)

*WATKIN, H., Woodleigh, Porthill, Stoke-on-Trent ... ... (1900-01)
WATKIN, T., Harding Terrace, Sheppard Street, Stoke-on-Trent... (1904-05)
WATTS, A. S., Mines Building, O.S.U., Columbus, Ohio, U.S.A. (1910-11)
WEBSTER, J. C., Bridge Pass, Victoria Road, Tunstall ... ... (1910-11)
WEBSTER, JAS., 15, Peele Street, Tunstall ... ... (1913-14)
WEDGWOOD (Miss) A., The Woodhouse, Cheadle, Staffs. ... (1916-17)
WEDGWOOD, ERNEST, B., The Grove, Wolstanton ... ... (1916-17)
*WEDGWOOD, F. H., c/o Josiah Wedgwood & Sons, Ltd., Etruria, Stoke-on-Trent ... ... (1905-06)
WELLS, J. H., "Tralee," Sketty Road, Swansea ... ... (1916-17)
WENGER, A. F., Victoria House, Newcastle, Staffs. ... ... (1905-06)
WENGER, A. H., Trentham Priory, Staffs. ... ... (1902-03)
WENGER, F. E., The Brampton, Newcastle, Staffs. ... ... (1905-06)
WHIRTER, JAMES MAC, Elsinore, Milngarvie, Dumbartonshire (1917-18)
WHITFIELD, T. S., c/o The Cobridge Brick Co., Burslem ... (1905-06)
WICKS, H., Cliff House, Wordsley, Stourbridge ... ... (1911-12)
WIGAN COAL & IRON Co., Wigan ... ... (1916-17)
WILD, ARTHUR, Hawthorn Dene, Hathersage ... ... (1916-17)
WILD, R., The Wrose Hill Fireclay Co., Ltd., Car Lane, Shipley, Yorks. ... ... (1916-17)
WILLIAMS, C. P., c/o Messrs. John Lysaght, Ltd., Normanby Park Steel Works, Scunthorpe, Lincolnshire ... ... (1916-17)
WILLIAMS, F. R., "Enderley," Princes Road, Hartshill, Stoke-on-Trent ... ... (1902-03)
WILLIAMS, F. W., 4, Rosslyn Road, Longton ... ... (1905-06)
WILLIAMSON, S. W., 1, Mansion House Drive, Shelleston, Glasgow ... ... (1917-18)
*WILSON, S. T., Park Works, Fenton, Staffs. ... ... (1904-05)
WITTON FIREBRICK Co., Ltd., Wear Valley Junction, near Darlington ... ... (1916-17)
WILKINSON & SON, S., Blackley Fireclay Works, Elland, Yorks. (1916-17)
WILTSHAW, C., Carlton Works, Copeland Street, Stoke-on-Trent (1916-17)
WINKLE, L. H., Colonial Pottery, Stoke-on-Trent ... ... (1908-09)
*WOOD, H. E., Hillside, Hamil Road, Burslem ... ... (1900-01)
WOOD, H. F., Dimsdale House, Wolstanton, Staffs. ... ... (1911-12)
WOODWARD, A., Prince of Wales Pottery, Sutherland Road, Longton ... ... (1917-18)
WOOLLAM, H., 53, Pinnox Street, Tunstall ... ... (1900-01)
WORKINGTON IRON & STEEL Co., Ltd., Moss Bay, Workington (1916-17)
WORTHINGTON, F. S., 5, Havelock Place, Shelton, Hanley ... (1907-08)
WRAGG, ROBT., & SONS, Storrs' Fireclay Works, Loxley, near Sheffield ... ... (1916-17)
WRAGG, THOS., & SONS, Swadlincote ... ... (1917-18)
WRIGHT, J. E., 153, Cauldon Road, Hanley ... ... (1914-15)
YORKSHIRE SILICA FIREBRICK WORKS, Oughtibridge, Sheffield ... ... (1916-17)

The numbers in brackets denote the session of election.

Any change of postal address should be communicated to the Assistant Secretary,

A. RIGBY, Pottery Laboratory, Stoke-on-Trent.

Hon. Members.

The following members are now serving with H.M. Forces, and have been elected Hon. Members for the period of the War :—

BAILEY, P.
BALL, S. R.
BARKBY, H.
BLIZZARD, A.
BLOORE, R. B.
BROWN, F.
BROWN, H.
CAMPBELL, A. J.
CARNALL, F.
CARTER, R. C.
CLEVERLEY, WM.
CODLING, B. P.
COTTON, A.
CULLINAN, R. V.
DAWES, W. A. S.
DAWSON, A
GILL, W. R.
GREEN, J. C.
GREGORY, HAROLD.
GRIMWADE, S. A.
GRICE, E.
HAMPTON, T. E.
HAWLEY, E.
HAWTHORN H.
HAWTHORN, S. J.
HEWITT, A. E.
HILL, ALFRED
JOHNSON, H.
JONES, E. O.
MOORE, BERNARD J.
PERRY, T.
RIDGWAY, B.
SAYER, JAMES
SHORTER, J. G.
STEELE, H. L.
STEVENSON, H. W.
STRINGER, G. E.
TAYLOR, F. E.
TAYLOR, T. M.
TAYLOR, J. F.
THOMAS, C. W.
TILL, H. H.
TOWNSEND, H.
UNWIN, A. J.
WALMSLEY, J. H.
WENGER, F. E.
WRIGHT, J. E.

Serving with the French Army :—

CHAVANE, M.

Killed in Action.

EVANS, A. G.
MEIR, G. E
LATIMER, A.
FLEMING, J. H.

Proceedings.—Session 1917-18.

General Meeting held in Central Technical Schools, Stoke-on-Trent, on Saturday, 15th September, 1917. Chairman: Mr. A. LEESE. Attendance 30. Messrs. H. L. Hartley, S. Newman, A. T. Green, and Robt. Parry, were proposed for membership. Mr. C. P. Shah read a paper entitled "The Effect of Magnesia Glazes on U.G. Colours." Messrs. F. S. Worthington, A. Heath, and A. G. Richardson contributed to the discussion. Mr. E. Watkin read a paper entitled "The Effect of Pressure on Tensile Strength, Porosity, and Contraction." Messrs. A. Heath, A. H. Ryles, F. Jones, W. Emery, and W. Simpson took part in the discussion.

Open Meeting held in the Central Technical Schools, Stoke-on-Trent, on Saturday, 13th October, 1917. Chairman: Mr. A. CLIFF. Attendance 64. Several ladies were present at the meeting. The following new members were proposed:—Collective members: Messrs. Campbell & Co., Falkirk, The Castlecary Fireclay Co., P. & M. Hurll, Ltd., Glasgow, Barr & Stroud, Ltd., Glasgow, Coltness Iron Co., Ltd.; Individual members: Messrs. J. W. B. Allen, S. W. Williamson, A. Macfarlane, J. D. Hamilton, W. Campbell, F. J. Alsop, A. Woodward, A. K. Foote, T. Linstrum, J. Loudon, J. MacWhirter, F. Morrall, W. M. Bakewell, G. T. Hallam. Mr. T. A. Acton gave a lecture on "The Roman Potteries and Kilns at Holt on the River Dee," illustrating his words by lantern slides and models. Messrs. T. H. Birchall, B. Moore, A. Leese, and Dr. Mellor also spoke on the subject.

General Meeting held in the Technical Schools, Stoke-on-Trent, on Saturday, 10th November, 1917. Chairman: Mr. B. MOORE. Attendance 35. Messrs. W. Davies, C. S. Garland, W. Heaton, and F. W. Hill were proposed as new members. Dr. Mellor read an epitome of a paper entitled "The Vapour Pressure of Clays," by Messrs. P. S. Devereux and J. E. Foster. Mr. E. W. T. Mayer read a paper entitled "Study in Chrome-Tin Pink." Mr. W. F. Yates read a paper entitled "Studies of Bone China Bodies." Part II. Short discussions followed the papers.

General meeting held in the Central Technical Schools, Stoke-on-Trent, on Saturday, 8th December, 1917. Chairman: Mr. D. F. W. BISHOP. Attendance 46. The following new rule was passed, "That members of the Council be elected for three years, four members to retire each year, and that the retiring members be eligible for re-election." The following new members were proposed:—Collective members: The United Alkali Co., Ltd., The South Metropolitan Gas Co.; Individual members: Messrs. J. Reid, J. Gibson, W. Hutton, D. M. Maclay, E. S. Clark, R. W. Phillips, W. H. Edwards, J. H. Price, F. J. Grocott, Dr. J. A. Jeffrey, Dr. A. Scott, J. S. Mitchell, and H. M. Ridge. Two papers were communicated by title: "The Inversions in Silica Bricks," Dr. A. Scott, and "Manufacturing Refractory Materials from Fused Bauxite," Noel Lecesne. Mr. H. J. Plant read a paper on "The Milling of Pottery Materials." In the discussion which followed, Messrs. D. F. W. Bishop, A. Heath, C. E. Ramsden, A. Leese, W. E. Goodwin, and W. F. Malkin also spoke on this subject.

Proceedings of the Refractory Materials Section of The Ceramic Society.

Meeting held in the Societies' Room, the Royal Technical College, George Street, Glasgow. Chairman: Tuesday, 2nd October, 1917, THE PRESIDENT. The Chairman remarked that he was very gratified to see so large an attendance, which showed an increasing interest was being taken in refractory materials, and having regard to all that refractory material makers have accomplished in these trying times it was indicative of the increased interest in the studies of all matters regarding refractories.

The following papers were read:—"The Distribution and Geological Position of the Valuable Fireclays and Ganisters of the South of Scotland," by Messrs. Lionel W. Hinxman, B.A., F.R.S.E., and Murray Macgregor, M.A., B.Sc.; "Refractories and Modern Kilns," by Mr. J. G. Maxwell; "The Refractory Properties of Silica," by Messrs. H. Le Chatelier and B. Bogitch; "The Testing of Refractories," by Dr. J. W. Mellor.

President—
Mr. W. J. Jones.

Secretary—
Dr. J. W. Mellor.

Flash-light Photograph taken at the Dinner of the Refractory Materials Section,
Glasgow, October 2nd, 1917.

The following papers were communicated by title:—"The Rate of Reaction (Vitrification) of Different Forms of Silica," by Messrs. P. S. Devereux and J. E. Foster; "A Comparison of the Porosity and Contraction of Firebricks made with Wet and Dry Grog," by Miss C. Beveridge and Mr. W. Emery; "The Rate of Hydration of Calcined Dolomite," by Messrs. C. Edwards and A. Rigby.

In the evening a dinner was held at the restaurant of Messrs. Ferguson & Forrester. The President occupied the chair. The illustration shows a portion of the dinner party. It was found impossible to have a photograph of the whole room.

MAJOR THOMAS, in responding to the toast of "The Imperial Forces," said:—

> I feel extremely honoured indeed that I have been asked to respond to this toast, but I feel quite unequal to doing it justice.
>
> As the Chairman has said, the deeds of the brave men who have been fighting for us in this war are beyond description and beyond praise. I, unfortunately, have been unable to take part in the actual fighting. Until lately I have been engaged on the training side, and in that capacity I have watched some thousands of the raw material of which the new Armies have been made, from the beginning of their training until the time they have gone overseas as the finished article. I can honestly say that my pleasure at the way these men have developed under training has only been equalled by my admiration of the way they have behaved on the other side of the water. As I have said, I do not feel at all adequate to responding to such a toast as this, and I may add that I do not believe any single person could do justice to it. The times we have lived in during the last three years have been the most extraordinary times ever lived in on this planet, and it is beyond question that only the most extraordinary energy and effort on the part of all of us will avail to readjust our world on a proper basis.
>
> As you no doubt remember, the Chief of Staff has said that the one thing the authorities consider essential to make our success what it should be, is, that the fighting forces should have behind them the full strength and will of the nation. I think this point wants bringing home and keeping permanently before everyone until the successful end, which we all look forward to, is brought about.

On behalf of the British Sailors and Soldiers I have to thank you very heartily for the way you have received the toast.

Mr. HERBERT BEARD (President of the West of Scotland Iron and Steel Institute), in rising to propose the toast of "The Ceramic Society," said:—

In the words of the Psalmist, to-night your hands are delivered from the pots. You are here to enjoy yourselves after the strenuous work of your earlier conferences in the day. I am quite sure that you have enjoyed your visit to Glasgow. As representing the West of Scotland Iron and Steel Institute, I think it is very wise on the part of your Society that you should set up a Refractory Materials Section. The materials you supply have got to be scientifically examined in preparation for their use in iron and steel works. I happen to live in a fireclay district, the Gartcosh, Garnkirk and Glenboig district, and I remember very well, when I first came to Scotland more than a quarter of a century ago, that bricks were sent along from the adjoining firebrick works to be tested in our puddling furnaces at Gartcosh. I understand that you are coming to something better than that, you are coming to make your tests more scientifically, and I am quite sure that it will be a great advantage. Of course the materials that you deal with were at one time of comparatively little value, so much depended upon the skill of the workman to make them suitable for the purposes required. We shall agree it is necessary there should be a close association between manufacturers of refractories and those who use them, and I am certain that as a result of your conferences to-day that that will be achieved.

In submitting this toast to you I shall remind those present that Dr. Mellor is really responsible for the creation of your Society, at the same time your President, Mr. Jones, takes the keenest interest in its doings and progress.

Gentlemen, I give you "The Ceramic Society," especially the Refractory Materials Section, coupled with the name of your esteemed President, Mr. Jones.

THE PRESIDENT, in responding to the toast of "The Ceramic Society," said:—

When, on February 9th last, I attended a meeting of the West of Scotland Iron and Steel Institute in the Royal Technical College of this city, I did not dream that in the

following October I should be addressing an audience in Glasgow in the capacity of President of the Ceramic Society.

The personal honour which this Society did me last May at the Stourbridge meeting by electing me as its President, is fully appreciated. I can only regard it as conveying a recognition by the members of this Society of my desire to act fairly and impartially while at the Ministry of Munitions, and of any efforts I may have made to promote the prosecution of research work useful alike to manufacturers and consumers, rather than because of my fitness in any other direction for the Presidential Office.

The Ceramic Society has now been established some 17 years. During that period it has widened its sphere of usefulness. Founded originally as the North Staffordshire Ceramic Society, and continued from 1903 to 1916 as the English Ceramic Society, it has now become The Ceramic Society. I am glad to say that we count among our members some of the most distinguished men in different countries throughout the world who have identified themselves with this industry.

By broadening the scope of its activities in the formation of a special Refractory Materials Section, The Ceramic Society has read rightly the signs of the times and acted wisely. We have met together to-day to discuss these matters of national interest, particularly in connection with the manufacture and employment of refractory materials.

Apart from obtaining most useful contributions by men in our own country who specialise in different branches of the subject of refractory materials and all that is incidental to their production, the establishment of a system for obtaining important abstracts from foreign journals showing progress made in other countries, is of the greatest value and should be extended.

For over three years we have lived and are still living under abnormal international conditions. We are citizens in a country which has taken, and is still taking, a leading part in the greatest conflict the world has ever known, and upon the ultimate success of which rests the future destiny of most of the nations of the earth. We have passed, and are passing, through an experience which none can afford to ignore, much less forget. For many years prior to 1914 we were engaged in an economic conflict with Germany, during which time she showed herself resourceful, adaptable, persevering, and aggressive—extending her influence and

commerce to the farthest corners of the earth and dispossessing us of many of our markets.

That aggressiveness and the success which attended it stimulated arrogance and a lust of territorial conquest, culminating in the terrible war in which we are still engaged. Although the end is not yet in sight, we must feel that signs are not wanting that the dawn of peace will soon be breaking and that the long night of sorrow and anxiety is surely—if slowly—coming to an end.

It is well for this nation that the clash came when it did. It was inevitable, and had it been longer deferred we should probably have been taken at even greater disadvantage than we were.

This fearful struggle for our future freedom and the freedom of the world has necessitated the nation putting forth its whole strength and mind and will. If the war has taught us one thing more than another it is that the great effort put forth must be continued, and that we must not relapse into our former condition of lethargy when the war is over.

What were the pre-war conditions in regard to the refractory materials industry in which we are all interested?

Very little organized research work had been *done.* A certain amount had been *initiated* at Stoke and Leeds, but on comparatively narrow lines. No serious effort had been made to provide the funds necessary to employ the skill of men able and willing to carry on investigation in regard to refractories as applied to so many and varied industries.

On every hand there are signs of industrial unrest. Although our own industry was fortunate enough to avoid an actual strike, the threat of one was unsettling and vexatious. Outside our own industry strikes took place of miners, railway men, carters, dockers, and others.

On the part of the employers there was an absence of co-operation for the general good and for the betterment of the industry as a whole. There is a marked difference between co-operation and aggressive combination. Co-operation makes for nothing but progress and the general good, it stimulates effort, removes jealousy and ill-will, widens one's horizon, and fosters contentment. Combination retards progress, stifles effort, creates jealousy, and narrows one's outlook, and almost invariably results in reactions of bitter price cutting during those ebbing periods of trade depression which invariably follow waves of prosperity. It is in good times that we should be careful to make progress in quality and methods of manufacture, the better

to fit us to withstand the difficulties and hardships of bad times.

They say our best friends are those who tell us our faults. As a friend of the refractory materials industry I cannot forbear an expression of opinion that some manufacturers of refractories in the past have been disposed to take too narrow an outlook. I have observed time and again an absence of that breadth of view which makes for progress; I have noted the existence of petty jealousies that obscure the vision; there has been a lack of co-ordination for justifiable and worthy purposes.

The remark does not apply to all—but I should much like to see a development of that good feeling that should exist throughout the industry. It is more than ever necessary at the present time, and the future success of the industry depends upon it.

Manufacturers, moreover, must study always the needs of the user, and must constantly endeavour to adapt their methods and materials according to such needs. There has been far too great a tendency hitherto to rest satisfied with things as they found them, and which were good enough for their fathers and grandfathers before them. "The world does move," and in industrial directions the recognition of this fact is the keynote of progress and success. From a trade point of view the period of the war may be said to have been one of good times for makers of refractory materials, whatever you may try to convince me to the contrary. All, or nearly all works have been kept fully employed. There have been many and great difficulties to contend with, but this was unavoidable. We cannot go through a terrible and devastating war for over three years, with five millions of the finest men of our country detached from their regular avocations, and expect that those remaining at home shall suffer no inconvenience. The wonder is that we have managed so well as we have. It is a tribute to the adaptability and loyalty alike of the masters and workmen who remained to carry on that so much has indeed been accomplished.

And what has been accomplished by refractory materials makers during the war? What demands have arisen, and been met, by the sudden and changed circumstances brought about by the titanic conflict into which we were suddenly forced against our will?

A great expansion of output was essential. The main reason for this was the increased pressure at which furnaces,

and plant of all kinds, was worked—often at higher temperatures than normally. This was not confined to the output of steel, but equally applied to furnaces producing non-ferrous metals, glass, and everything that is necessary where heat treatment is required to produce those materials which were essential to the conduct of this war.

Further, vast extensions to works of different kinds had to be undertaken in all directions, and all of a most pressing nature. This involved an increased output of materials of every description.

The wave of patriotism which swept the country at the outbreak of the war denuded the works of large numbers of their most capable men; but notwithstanding all this, and notwithstanding added difficulties due to shortage of wagons, congested railways, inability to obtain materials readily, priority certificate troubles, increased office work with depleted staffs, and many other worries and annoyances, the output of firebricks has been increased 20 per cent., coke oven bricks by over 100 per cent., silica bricks by over 60 per cent., calcined dolomite by 80 per cent.

Magnesite bricks for basic steel furnaces and other purposes were nearly all obtained from Austria before the war. Since then we have not only had to meet the emergency quickly, and make all that were required for our own needs, but we have kept our Allies supplied, and have had to send magnesite bricks to neutral countries from whom we and our Allies were obtaining essential materials. We have improved the quality also as we went on. I have every reason to be proud of the way in which the makers have carried on, and the refractory material makers of the country have reason to be satisfied with the part they have played to meet the suddenly increased demands made upon them. Any failure on their part would have been serious, and would have prevented that expansion of this country's output of steel, which was about $7\frac{1}{2}$ million tons of ingots, immediately before the war, is now 10 million tons, and will be over 12 million tons by the end of next year. Of their share in bringing about these results refractories manufacturers may justly be proud.

But to forget or fail to profit by the lessons of the war would be unpardonable. And the main lesson as I see it is this.

There is a great need for much closer co-operation between the producers and the consumers, and the link which will bind them together is the scientist and his investigation and research work. The needs of the user

must be carefully studied, every effort must be bent toward the production of the highest quality of refractory possible, suitable for the special work under particular conditions which it has to perform. In this work the scientist must play the prominent part. The manufacturer must enlist his assistance to the utmost extent, and never cease to endeavour to attain to the ideal by continuous experiment.

The work of the practical scientist is to ascertain how to use the natural forces, and the materials at our disposal, to the best advantage; in other words, to indicate the most economical and effective methods of obtaining the desired ends

For instance, where heat is required to be applied for reduction purposes, whether it be in a steel melting furnace or a gas retort, it will generally be found to be true that the greater the heat applied the more rapid and satisfactory are both the process and the result. In this respect it may be said that the tendency in matters of heat treatment is in the direction of higher working temperatures.

The manufacturer finds himself compelled to turn to the scientist for assistance to enable him to meet the demand for an improved product required for the purpose of effecting an economy already discovered.

It becomes the obligation of the refractory materials maker, whether he views it from the narrow standpoint of selfishness or from the broader standpoint of national necessity, to seek the aid of the trained scientist, the better to enable him to effect such modifications in his methods of manufacture as will enable him to furnish the improved material demanded by progress in methods in other directions.

For this reason, I urge that a well ordered, comprehensive, and thorough scheme of scientific research in regard to refractory materials should be instituted and should receive the ungrudging support of all the members of this Society, in common with all those other societies affected or interested Further, the importance of such research should be recognised by the State as a national necessity, and should be liberally assisted accordingly.

I am glad to say that a serious attempt is being made to launch such a scheme on a national basis, and I commend the effort to the very active and generous support of the members of this Society. I am satisfied that research work is a splendid investment. And it must always be borne in mind that much more can be accomplished by joint effort, and much more liberal expenditure can be provided for

scientific and industrial research by collective rather than by individual effort.

There is much to be done by way of improvement in quality of firebricks, coke oven bricks, silica and magnesite bricks; retorts of all kinds; crucibles; and furnace materials generally. Scientific investigation is urgently required into processes and methods of manufacture, the grading, blending, mixing, moulding, drying, settings, and burning operations; by methodical enquiry and observation into the chemical and physical changes in refractories under varying working conditions. Nor does it stop here. The scientific management of works, including the handling and distribution of materials to secure greater efficiency and proper economy, is as important a subject of investigation and correction as the actual details of the manufacture of products. I am convinced *enormous* savings can be effected in most works in fuel consumption by well designed, carefully constructed and efficiently worked kilns, including the application of the improvements effected by way of gaseous or semi-gaseous firing. In all directions scientific and systematic observation and investigation will yield the largest measure of successful results.

In addition to those matters of research with a view to the improvement in quality of output in order to meet the more exacting conditions demanded by scientific progress in other directions, it is incumbent upon the employer to pay a greater regard for the welfare of his workpeople, to do all that he can to secure an improved state of body and of mind, and to take an interest in their general welfare during, and also outside, their working hours. After all, the manufacturer is absolutely dependent on the efforts of his employees. If they are not with him in a spirit of co-operation and loyalty his best laid plans are foredoomed to comparative if not absolute failure.

The greatest economy in any works is to possess a community of workpeople who have a joint interest with their employer in the success and prosperity of the venture. The only way to secure this is to make their lives your own interest.

Doubtless many here have read the reports of the Commissions of enquiry into industrial unrest. Those who have not done so should obtain and study them. Leaving out those causes directly attributable to war conditions, it will be found that the other causes are a lack of fraternal interest between employer and employed, and a tendency to exploit the worker, as though labour possessed no rights.

The employer who is careful of the welfare of his employees is the one who will win through. He must recognise that to-day the workers of the country are better educated and take more interest in economic questions, their views are broadening, and they require better conditions under which to live. Men are not content with things as they were in days gone by; they want a share in this world's comforts, and I don't blame them. There is an old Mosaic law, I think, which says, "That which is altogether just shalt thou follow that thou mayest live." The words are old, the spirit of them is ever new. The employer who realises this and acts accordingly is less likely to be troubled with the brutal arbitrament of strikes, and he may rest assured that the greatest asset in his business is the possession of contented workpeople, which has been secured by his having made their interests and his own identical.

In conclusion, we must be more self-supporting. The great industries of this country must not depend upon foreign nations. We must develop our own resources and those of our Colonies. We must be in the van of progress the whole time. There is room for all who are bent upon marching with the times, but none for those who "slack." The advantages of healthy rivalry are great and permanent, co-operation is infinitely better than combination, it is the broad view as contrasted with the narrow view. Those brave men who have gone forth and made the supreme sacrifice took the broad view, they have done so for their country, for the maintenance of her premier position, to secure the freedom and welfare of us and of those whom they left behind, and who shall succeed them hereafter. It is our duty to take the broadest possible view and to co-operate on broad lines. The Ceramic Society has a record of good work to look back upon. The opportunity is now before it of accomplishing greater things in the future.

I cannot close without paying a tribute to the immense amount of work which our good friend Dr. Mellor has done for this Society, and for the industries of this country. We all know how much he has at heart the welfare of The Ceramic Society and all that appertains to it; no member has ever gone to him for help or advice and come away unassisted, he lives for his work and that alone, without a thought of gain of any kind.

We have also to thank Mr. Wink Wight and those Scotch friends who have made all the arrangements and have worked so hard to promote the success of this meeting.

The President had to leave to catch the night express to London and Dr. Mellor took the Chair.

Mr. WALTER DIXON, in response to a call from the Chair, said:—

That while he had not expected to be called upon for any remarks, he could not let the occasion pass without an expression of satisfaction at the obvious success and benefits which would result from such a large and representative meeting of interested parties from the whole of the areas included in the industry. Amidst the horrors and miseries of the war, it was impossible to disregard the many signs and evidences of beneficent results which would accrue through this terrible clash of arms . . . . beneficent results, not only to the soul and spirit of the nation, both collectively and individually, but also to every phase and condition of our communal life. The conference in which they were at present engaged, bringing together as it did parties engaged in the same industry, who have hitherto been more or less unknown and "stand-offish" and competitive with each other, into close and friendly relationship, was only one of many outstanding examples of the new spirit which is abroad.

It appeared to him that, while appreciating and realising the benefits which would accrue from such combinations, the obligations and possible dangers incidental to such should not be lost sight of. We have been face to face for many years in our industrial capacity with the power which comes of combination of interests and aims. and we had of late seen its working results in a more sanguinary phrase. In other words, we have seen the efforts of a nation which had either intuitively or otherwise sunk its individuality, and made itself the tool of an autocratic leadership Against this, and without attempting to gauge or measure its success or attainments, it behoved us, he thought, to remember that we were members of a nation who owed their attainments probably in the main to individual as apart from collective efforts. No Britisher ever had, or he hoped and believed ever would be, other than proud of his nationality, and would always have cause to be proud of it, so long as individualism—the "John-Bullism," if he might use such a term—was allowed to have its play. It was this element which had brought us as a nation to what we were, and would keep us for all time where we were. It was because of this that it appeared to him necessary to emphasise the desirability of maintaining

it amidst all the collective efforts and combinations which were being made within the various trades themselves, and which were being encouraged both sentimentally and tangibly by our Government at the present time. Individualism was what had accomplished all that was best and most worthy, and a sinking of this individualism, or the making of conditions which should stunt and confine this individualism would be to the detriment, if not the death, of our industries. It was in this sense that he felt there was danger ahead in Government control of or interference with our industries. We were at present living in abnormal times and under abnormal conditions, and therefore, without any reference to the present times, he believed that in this country, Government help with Government control would be dearly bought. Nor did he think it possible in such a country as our own to place an industry under the control of any Government official or officialism which would not be to the detriment of the progress, rise and development of such industry. Government officialism and Government officials in normal times and normal conditions lived through and by what Gilbert once expressed as "doing nothing in particular, and doing it very well." Government officials, as everybody knew, who had had to deal with them, each in his own sphere and department, lived mainly by shirking or handing on responsibility to other parties, and innovation was *per se* troublesome and anathema. In worldly matters, "the way of transgressors is hard." In industrial matters, and where Government officialism is concerned, the way of an innovator, an inventor, an improver is doubly hard. To this end, therefore, he (Mr. Dixon) felt it was necessary that we should not lose sight of the fact that, just as our country had in the past, so it would in the future, maintain any pre-eminence which came to it by freedom and individuality, not by control and collectivism. Let us take all the good that was possible out of such combined interests as there was evidence of here to-night, but let us never lose sight of the fact that individualism and the individuality of a "John Bull" was what was of real worth in our nation.

A very enjoyable evening was brought to a close by singing "Auld Lang Syne."

On Wednesday, 3rd October, a business meeting was held. Mr. JOHN HURLL presided in the unavoidable absence of the President. The Minutes of the last meeting were read and confirmed. Prof. H. Le Chatelier (Paris) and Prof. O. Rebuffat (Naples) were elected honorary members of the Society. It was decided that the Spring (1918) Meeting be

held at Sheffield, and the Autumn Meeting at Cardiff. Mr. G. Wink Wight was elected a member of the Council. Mr. G. Wink Wight, C.A., read a paper entitled "General Organization of Firebrick Works."

In the afternoon the members visited the Dalzell Steel Works, Motherwell, by kind invitation of the Directors of Messrs. David Colville & Sons, Ltd. The visitors were shown specimens of all kinds of refractory materials (before and after use) from different localities, and inspected the open-hearth melting furnaces (in actual working, and under repair) and heating furnaces for the various mills. The importance of refractories in the iron and steel industry is strikingly illustrated by the statement that for the maintenance of the company's works the quantity of firebricks required per annum is 5,000,000, with 8,000,000 silica bricks, 200,000 magnesite bricks, 45,000 chromite bricks, and over 10,000 tons of refractory sand. The members were delighted with the exhibit of refractory materials, and greatly impressed with the engineering skill by which large masses of hot iron were tossed, rolled, twisted, and tortured by the various machines. One member just after he had jumped as far as he could from a conveyor transporting a big block of red-hot iron, was heard to mutter:—

> We cam' na here to view your warks
> In hopes to be mair wise,
> But only, lest we gang to hell,
> It may be nair surprise.—BOBBY BURNS.

In the evening Mr. J. Burton delivered a popular lecture on "The Theory and Practice of Firing," at the close of which Dr. DESCH (who presided) remarked:—

> We have had this evening a most interesting discourse from Mr. Burton. He has shown us the variety of problems which exist in relation to the firing, and has shown very clearly the lines necessary to follow in making improvements which, in view of the facts he has given us as to heat efficiency, I think we must say it stands in some need of. Mr. Burton has shown the importance of a thorough study of the conditions. The papers read at the meeting call attention to the need of further study, and I hope they will lay the foundation of a good deal of work in this country and elsewhere. Dr. Mellor did sketch yesterday the outline of a Utopia where firing will not be needed, but until the time comes we shall be dependent on the firing, and the improvement of firing seems to be one of the most urgent questions we can tackle at present. I am sure I shall be expressing your wishes when I say we are most deeply indebted to Mr. Burton.

Proceedings—Session 1917-18.

General Meeting held in the Central Technical Schools on Saturday, 19th January, 1918. Chairman: Mr. A. G. RICHARDSON. Attendance 45. The Chairman welcomed the Artists who were present by invitation. The following members were proposed:—Messrs. The Eglinton Silica Brick Company, Messrs. H. Ogale, W. Anderson, J. H. Henderson, T. H. Sandland, and T. G. Simpson. An announcement was made from the Chair that £160 had been subscribed in response to the Special Appeal. Two papers were communicated by title, namely, "Refractory Properties of Magnesia," by Messrs. H. le Chatelier and E. Bogitch, and "A Microscopic Study of the Bone China Body," by Prof. Cronshaw. Mr. A. E. Gray opened a discussion on "The Encouragement of Art in the Potteries." The following members also took part in the discussion:—Messrs. A. G. Richardson, F. Jones, G. Lester, S. Thorogood, T. H. Sandland, A. J. Vaughan, A. Heath, A. Leese, F. R. Williams, C. P. Shah, and Dr. J. W. Mellor. Members and others who were interested in the formation of an Art Section of the The Ceramic Society were invited to remain after the meeting to discuss the subject.

General Meeting held in the Central Technical Schools on Saturday, 9th February, 1918. Mr. BERNARD MOORE presided over a meeting of 50 members. The Chairman welcomed the members of the North Staffs. Mining Institute. Mr. J. M. Draper, of the Rhondda Mining and Engineering Company read a paper entitled "Brief Notes on Hydraulic Separation as applied to Fine Coals, Clays and Shales." Messrs. B. J. Allen, E. Evans, and E. M. Myers took part in the discussion. On the motion of Mr. W. Simons, seconded by Dr. J. W. Mellor, a hearty vote of thanks was passed to Mr. Draper. Mr. H. S. Newman communicated by title of "The Graphic Representation of Quarternary Mixtures." Dr. J. W. Mellor read a paper entitled "The Deterioration of Moulds during Storage." The following new members were proposed: Miss J. M. Wallace, Messrs. E. Sadler, H. T. Robinson, A. Ridout, E. M. Bradford, and P. N. F. Sheppard.

General Meeting held in the Central Schools of Science and Technology, Stoke-on-Trent, on Saturday, 9th March, 1918. Chairman: Mr. J. A. AUDLEY. Attendance 30. The following

new members were proposed:—Messrs. J. J. Huntbach, J. Dolby, P. Sailly, Wm. Gilbert, H. Riley, J. F. Krebiel, G. N. Cook, G. R. Bolsover, F. Robinson, G. W. Hewson, H. Lloyd, C. Davie, and W. Hancock. Mr. W. Donald read a paper entitled "Magnesite and Magnesite Bricks." Mr. W. Emery read some conclusions on this subject arrived at by Dr. A. Scott. Messrs. J. A. Audley, W. J. Brooke, J. W. Mellor, and G. Lester took part in the discussion.

Meeting held in the Central Technical Schools, Stoke-on-Trent, Saturday, 13th April, 1918. Chairman: Mr. A. G. RICHARDSON. Attendance 46. The following new members were proposed:—Messrs. E. H. Lewis, N. B. Davis, F. Lax, A. H. Adams, C. B. Chatres and A. C. Edwards. Mr. Bernard Moore read a paper entitled "The Bending of Easy Fired Ware." The Chairman, Dr. Mellor, and Mr. C. E. Ramsden contributed to the discussion.

Annual Meeting held in the Central Technical Schools on Saturday, 11th May, 1918. Chairman: Mr. D. F. W. Bishop. Attendance 27. The officers for the Session 1918–19 were elected as follows:—*President*: Mr. R. L. Johnson; *Vice-President*: Mr. J. A. Callcott; *Publication Committee*: Mr. F. Turner *vice* Mr. J. A. Audley; *Council*: Messrs. G. Adams, W. Emery, T. A. Simpson, and F. R. Williams for three years; Messrs. J. H. Colclough, A. J. Campbell, F. Jones, and A. G. Richardson for two years; Messrs. B. J. Allen, T. Bates, C. Edwards, and A. J. Vaughan for one year. All other officers were re-elected. A vote of thanks to the retiring officers was unanimously carried. The Council's Annual Report was adopted. The subscription for the next Session was fixed at 25/–. The following new members were proposed:—Messrs. Joseph Morton, Ltd., Messrs. Wm. Harriman & Company, Ltd., Messrs. S. Brayshaw, J. McCormick, H. Hinchliffs, W. R. Ormandy, D.Sc., C. A. King, E. Hartley, C. H. Moore, A. Whiteley, Wm. Pullwood, J. R. Lomax, C. R. Peregrine, H. Etchells, Wm. Hamilton, P. G. H. Boswell, G. J. Jackson, E. J. Noble, E. A. L. Pryer, and C. G. Fletcher. Dr. J. W. Mellor and Mr. W. Emery communicated by title "The Refractoriness of Firebricks under Load." Mr. W. Emery read a paper, written by Mr. F. Stirk, of Omdurman, entitled "Sudanese Pottery." Dr. Mellor and Mr. D. F. W. Bishop also spoke on this subject.

Council's Annual Report.

Gentlemen,

The membership of the Society is progressing at a great rate. We have now 448 ordinary members, and in addition there are 57 firms subscribing members.

The ordinary membership fee is much too low. The extra size of the Transactions, the considerable increase in the size of the Abstracts, and the considerable increases in cost of paper, led to the cost of the Transactions during the Session 1916–17 being about 2/6 higher than the ordinary subscription, and the Treasurer estimates that for 1917–18 the cost will be between 5/- and 7/6 higher than the subscription. Consequently, we should not have been able to continue without curtailing the Transactions and Abstracts had not a number of members generously subscribed £250 18s. (including £50 from the Pottery Manufacturers' Association and £30 from the Stourbridge Wages and Conciliation Board). It is estimated that this will probably put us right for the present Session, but the subscription must be raised or the Transactions diminished. The Council cannot recommend the latter course, and the only alternative is the former.

The Refractory Materials Section is in a highly prosperous condition, and a very successful meeting was held in Glasgow in the autumn of 1917. The Sheffield meeting, to be held next week, promises to maintain the high standard set by Mr. Wink Wight, Local Secretary for Scotland. Prof. Fearnsides and Mr. Cyrus Jones are the Local Secretaries for Sheffield, and the Council's thanks are due to Messrs. Wink Wight, Cyrus Jones and Prof. Fearnsides for their work in the interests of the Society.

We wish to thank the Governors of the Central School of Science and Technology, Stoke-on-Trent, also the authorities of the Royal Technical College, Glasgow, for the use of rooms.

F. R. Williams,

Chairman of Council.

May 11th, 1918.

List of Special Subscriptions.

	£	s.	d.
A. J. Vaughan	0	5	0
A. B. Searle	1	1	0
E. Steiger	0	10	0
R. H. H. Jones	0	10	6
Greville Jones	2	2	0
C. H. Heath	0	10	6
Alfred B. Jones & Sons	1	1	0
Himley Fire & Red Brick Co., Ltd.	5	0	0
E. Hughes & Co.	1	1	0
W. E. Hobbs	1	1	0
Middleton Fireclay Works	2	2	0
J. S. Whitfield	2	2	0
Geo. Blackwell & Sons, Ltd. ...	3	0	0
Summers & Sons, Ltd.	2	2	0
Grimwades, Ltd.	1	1	0
Pickford, Holland & Co., Ltd. ...	5	0	0
H. F. Wood	5	0	0
James C. Waterhouse	3	0	0
Witton Firebrick Co., Ltd.... ...	1	1	0
David Colville & Sons, Ltd. ...	5	0	0
Sir R. Hadfield	5	0	0
James Dougall & Sons...	5	0	0
Thomas Poole...	1	1	0
Eglinton Silica Brick Co., Ltd....	3	3	0
Tooth & Co.	0	10	6
Pountney & Co.	5	0	0
Woodall, Duckham & Co.	2	2	0
F. Turner...	0	5	0
Mr. Plant	0	5	0
H. S. Kirkland	0	10	6
G. Adams	0	10	0
A. Heath	0	5	0
Mr. Jones	0	2	6
W. Emery	0	10	0
F. R. Williams	1	1	0
A. Cliff	5	0	0
John Walker	1	1	0
F. G. Marshall	0	10	6
Bispham Hall Colliery Co.... ...	2	0	0
Adam Mason & Sons, Ltd.... ...	5	0	0
General Refractories Co., Ltd. ...	1	0	0
Ravenhead Sanitary Pipe Co. ...	2	2	0
Wigan Coal & Iron Co.	3	0	0
Miss Wedgwood	0	10	0
W. B. Cleverley, Junr.	0	10	6
Grindley & Co.	5	0	0
Steel, Peech, & Tozer, Ltd. ...	5	0	0
Gilbertson & Co., Ltd....	2	2	0
Bernard Moore	1	0	0
J. & R. Howie	2	2	0
G. W. Mottram	1	0	0
Farnley Iron Co., Ltd.	1	1	0
F. H. Wedgwood	5	0	0
Hathern Station Brick Co., Ltd.	2	2	0
The Morgan Crucible Co., Ltd.	5	0	0
S. Fielding & Co.	5	0	0
E. J. & J. Pearson, Ltd.	0	10	0
Wedgwood & Co., Ltd.	2	2	0
G. E. Stringer	2	2	0
J. H. Sankey & Sons, Ltd. ...	1	0	0
John Aynsley & Sons	5	0	0
Keeling & Walker	5	0	0
W. Benson & Son, Ltd.	2	2	0
The Lilleshall Co., Ltd.	2	2	0
A. G. Richardson	0	5	0
H. E. Wood	0	10	0
J. H. Davidson	1	0	0
Ernest Mayer	1	0	0
Brymbo Steel Co., Ltd.	2	2	0
Douglas Firebrick Co., Ltd. ...	2	2	0
T. A. Acton	2	2	0
The Meltham Silica Firebrick Co.	5	0	0
Sherlock, Smith & Co.	5	0	0
Brooks, Ltd.	5	0	0
K. O'Kura	1	0	0
S. Manders	1	2	0
J. Mitchell	2	2	0
	£171	0	0

Proceedings of the Refractory Materials Section of The Ceramic Society.

Meeting held in the Mappin Hall, Department of Applied Science, University, Sheffield, on Tuesday, the 14th May, 1918. Chairman: THE PRESIDENT. Dr. RIPPER, on behalf of the University authorities, welcomed the members to Sheffield, saying:—

> "I desire on behalf of the University authorities to offer you all, Mr. President and members, a very hearty welcome to this Mappin Hall. When this hall was first projected we knew it would be the centre of all kinds of useful and valuable work, and I do not know that I have ever been more interested in any gathering than that of this morning. I think a Society such as this is a wonderful sign of the times. We recognise how many elements there are in the success of our industries; we recognise the growing interests demanding our attention. I venture to think that a few years ago a Society such as this was never thought of, and yet we have to-day the best that science can give devoting its attention to investigation, research and discovery of knowledge; and we have eagerness on the part of those engaged in our industries to receive that knowledge, to use it, to operate with those engaged in the same industry, and these are attempts to promote the best for the industry as a whole. That is a splendid spirit, the determination to co-operate for the well-being of our industries. There is hardly any more interested example of that than the Society which I have the honour to see before me. You have a most interesting programme, an unusually excellent series of papers, and I venture to predict for these two days' meetings a great deal of success, and I am sure that at the end of it it will be my pleasure to congratulate you on the success of this meeting. Once more I offer you a very warm welcome on behalf of the University authorities."

The following papers were read:—"The Supplies of Refractory Materials available in the Sheffield District," by Prof. W. G. Fearnsides, followed by "Notes on the Evolution of the Ganister Industry in the Sheffield District," by Mr. J.

Holland; "The Constitution of Silica Bricks," and "A Micro-Study of Magnesite Bricks," by Dr. A. Scott; "The Essential Properties of Refractories used in Steel Production," by Mr. Alleyne Reynolds; "An advance towards Greater Economy of Fuel and Increased Output in the Deadburning of Magnesite and Dolomite and the Burning of Cement," by Mr. E. Steiger; "Silica Refractories and the Materials used in their Manufacture," and "On Refractory Materials derived from Bauxite (fused and crystalline)," by Prof. A. Bigot (read by Mr. W. J. Rees); "The Dissociation of Salt," by Mr. H. V. Thompson, M.A.; "Refractories in Gas Works from a User's Point of View," by Mr. J. P. Leather.

In the evening members and invited guests dined at the Grand Hotel. The Right Hon. the LORD MAYOR OF SHEFFIELD proposed the toast of "The Ceramic Society," and said:—

"I am very much obliged to you for your kind reception of me, but I am afraid that by the time I sit down you will not look upon me so graciously as you do now. As a matter of fact, I confess I never felt at a greater loss in proposing a toast than I do to-night. I know it is the most important toast of the evening, and I am quite aware that the Lord Mayor is the proper person to propose this toast, because he represents for the year of his office all the aims and interests of the city over which he happens to preside, but I am also aware that there are at least 100 men in this room who know a great deal more of this subject than the humble individual who addresses you. I am of course quite aware that anything that has to do with the steel industry is of the utmost importance to Sheffield and will command the interest of every Sheffield man, and if your Society, as I understand, is a Society which has to look after and to promote anything in connection with the making of crucibles and furnace linings, which are absolutely essential in the production of steel, then I have no hesitation in saying that we in Sheffield must be heart and soul interested in such a Society.

"I understand this Society, which started in a very small way, as most societies do, owes its development largely to the enthusiasm of Dr. Mellor. Dr. Mellor is one of those gentlemen who have bent their energies and abilities towards bettering and furthering the industries of the country. Coming from the Potteries, it is not unnatural that he should take an interest in all that appertains to clay,

and we quite see the connection between the subjects of his researches and the refractories which are of interest to this Society.

"Though the Society started in that small way it has now increased its membership to over 600, and not only has it increased its membership but it has widened the scope of its work. Quite naturally they have linked up with them the technical research which is to be found in our Universities, and one is pleased to think Sheffield has lent a helping hand. We are pleased to have with us to-night the Vice-Chancellor of the University, and the Pro-Chancellor, Mr. Alderman Hobson. It is pleasant to know that those who are interested in refractory materials in Sheffield have been good enough and wise enough in their generation (shall I say) to equip a laboratory at our University, and also that our steel magnates have guaranteed the salary of an expert. All that is good and must be to the benefit of such a Society as this. There is another great advantage, and that is, they are trying to co-ordinate the work of all similar societies, to co-ordinate the leaders of these societies and get them so far as they can into one Society so as to form one grand Society. Now I think that I have said enough with regard to the Society to show that this Society is a most useful Society in connection with the steel industry in which we are so greatly interested. I must not sit down without saying that Mr. W. J. Jones has done work of a very important character in connection with this Society. He has worked long, he has worked hard and gratuitously, and we owe a debt of gratitude to Mr. W. J. Jones for what he has been able to do, and is still doing, in connection with this Society. We are proud to have him here to-night. We in Sheffield recognise not a stranger but one of our friends, whom we are glad to welcome back and shake hands with as an old friend, and I have no hesistation in commending this toast for your very hearty acceptance, because I believe this Society is out for the good of important matters in connection with our steel industry, and for co-ordinating the various societies in different parts of the country, so that after the war we shall be able to present a bold front to the enemy and be better able to fight him.

"Gentlemen, I have now the very greatest possible pleasure in giving you the toast of 'The Ceramic Society, coupled with the name of the President.'"

THE PRESIDENT responded to the toast of "The Ceramic Society," saying:—

"I thank you heartily on behalf of The Ceramic Society for the way this toast has been proposed and received; I thank you personally for the reception you have accorded me.

"To me individually this meeting at Sheffield has afforded intense pleasure—I feel myself among friends and at home. For thirty years I was associated with a firm whose works and collieries are situated just outside Sheffield, whose name has borne a high reputation since its establishment in 1793. You can appreciate, therefore, that I claim to have known something of the important position occupied by Sheffield in the steel industry of this country, long before I had the privilige of knowing so many of the leading men in the Sheffield steel trade by reason of the exigencies of this war, and the minor part I have taken in the Steel Department of the Ministry of Munitions during the past two years.

"I was already aware of the discoveries and development of the steel industry made by such men as Allen, Bessemer, Fox, Vickers, Ellis, Wilson, Jessop, Firth, Hadfield, Arnold, Ripper, Capron, Saniter, and others, either Sheffield men, or men who have spent most of their working days here.

"Moreover, the recognised high value of the ganister mined in the Sheffield district in the manufacture of refractories makes it particularly fitting that the Refractory Materials Section of The Ceramic Society should hold its meeting in this city, and especially at this time, for nowhere is the great importance of the refractory materials industry more fully recognised, and nowhere has a more glorious part been played than by Sheffield men, both at the war and here at home, by providing the arms and implements which have enabled us and our Allies to withstand the furious onslaughts of a merciless and treacherous enemy both on land and sea, in the sea, and in the air.

"Not only is the consumption of refractory materials far greater in Sheffield district than in any other district of equal size in the country, averaging as it does in silica bricks alone some 1,143,000 per month, but the nature of its staple industries necessitates that the refractories used shall withstand more exacting conditions and trials.

"That the pioneers of the Sheffield steel industry have recognised this fully is shown by the nature of the work

done at the University of this city, and the recent establishment and equipment of a special department for the purpose, under the guidance of Professor Fearnsides, who is a comparatively young man full of enthusiasm and imagination.

"Then we have other well-equipped laboratories for scientific research into the properties of refractories at the Firth-Brown Research Laboratory, under the direction of Dr. Hatfield; the Hadfield Research Laboratory, under the direction of Mr. Milne; the laboratory at Steel, Peech & Tozer's Works, Ickles, under the direction of Mr. Saniter.

"Further to illustrate the recognition by the steelmakers of the district of the importance of the subject, I believe I am right in stating that a proposal was favourably entertained by them for a voluntary levy of so much for every thousand silica or other refractory bricks which entered their works, such levy to form a fund to be devoted to the furtherance of scientific research into the properties of refractory materials, with a view to improvement in their quality, manufacture, and application. The refractory makers have undertaken to equip the laboratory, and have paid over already between £500 and £600 towards this object.

"All this is very indicative of the spirit of progress which obtains to-day. It is a comparatively recent awakening.

"The refractory materials industry is the handmaiden of the steel industry, and shares in its prosperity or adversity.

"On a former occasion, when I was invited to meet a few of the representatives of the Sheffield steel industry, and when the relations between them and The Ceramic Society were perhaps not quite so happy and cordial as I believe them to be to-day, I ventured briefly, but very earnestly, to urge that my Sheffield friends would not hold themselves aloof and pursue a path divergent from the rest of us. I do not know if it is necessary to renew that invitation, I scarcely think it is. Your great kindness and hospitable reception fortify me in the belief that it is not.

"If we are to attain the greatest measure of success we must be closely associated. Unity of purpose makes for success. Absence of co-ordination and close co-operation retards progress. That has been amply demonstrated time and again in the terrible conflict in which we have been for so long, and are still, engaged; at last it has been rectified.

"The task before us is great and worthy—it is not a district or parochial task, it is national—it affects the steel and other metallurgical industries as a whole, it is an imperial question, to search for, to discover, and to apply processes

and methods which will enable us to keep our country in the forefront of the international competition which will surely recur sooner or later after the termination of hostilities.

"There is ample room for all workers. There may be many investigations which specially appeal to the Sheffield industries; by all means tackle them here, work them out completely, but do it as a co-ordinated part of a larger programme for the country's good, not for the good of a select few only. Many other investigations which can be conducted elsewhere at the same time as you are at work, can be completed and placed at your disposal; they will be invaluable to you as well as to others outside.

"You have exceptional facilities here for conducting practical experiments; laboratory experiments are very good and extremely valuable, but they have an awkward way of not always resolving exactly as you expect when applied on a large working scale.

"That the Germans are fully alive to the great importance of research work is clearly shown from the report of the annual meeting of their Iron and Steel Institute held at Dusseldorf in March of last year, and from the translation of which I will ask your permission to read one or two short extracts.

"The German scientific societies and industrial institutes have just formed 'The Kaiser Wilhelm Trust for the promotion of war science,' a trust which has received the Kaiser's blessing, and whose aim is to further the development of scientific and technical aids to warfare by uniting the scientific and military forces of the country for work together.

"I would fain hope that in the near future this country might have a 'King George Trust for the Promotion of Peace Science,' whose aim should be to assist British manufacturers on every technical subject which would help to promote the prosperity and welfare of this country.

"I have pleaded at every opportunity for closer working between the scientist, the manufacturer, and the consumer. I venture to repeat this advice. The days of empirical working are speedily passing, and clearly defined scientific methods must be adopted. Surely it would be counted folly for any man to set out in the dark to explore a difficult country unknown to him, and full of pitfalls. In the same way manufacturers will be foolish to continue to grope along, feeling their way in the dark, when they can

secure the bright light of science to direct their course, almost for the asking.

"I have great hopes still that a national movement will soon be launched in the direction I have indicated. It has been developing very slowly, but I trust the foundations upon which it will be erected are all the more massive and secure. You men of Sheffield must strongly support the movement, you must always keep in the forefront, and by supporting this national scheme you will be assisting yourselves to this end.

"This country has had to meet sudden emergencies—from the refractory materials point of view the advent of the war caused the immediate demand for increased supplies of all forms of steel and other metals for munition purposes and threw a sudden strain upon the makers of refractories (particularly of silica bricks), which was as great as it was entirely unexpected—but by a careful system of allocation, the cutting off of supplies altogether to industries who could make shift by substituting firebricks, and by extensions of the principal refractories works, we have succeeded in overcoming our difficulties and have managed to carry on. For many months there has been no shortage anywhere.

"I well remember my first visit to Sheffield, after my appointment at Ministry of Munitions, when I met the Sheffield silica brickmakers and called on them for great extensions to their output. They were a bit surprised, but they promptly rose to the needs of the situation and delivered the goods. At that time the country's output of silica bricks was about 7½ millions per month, to-day it is between 11 and 12 millions.

"Again the war found us in a very tight place for magnesite bricks for basic steel furnaces, as the bulk of our supplies had been procured from Austria and Germany. The British manufacturers, who had never been encouraged, also rose to the occasion, and to-day we are in a perfectly safe position, having larger stocks of magnesite bricks and of raw material than ever before, enough to last for a long time, and this notwithstanding an enormous increase in the number of furnaces making steel by the basic process. I am satisfied that the quality of the magnesite bricks now made is continually improving, and that we can in future be independent of supplies from our present enemies. The Ceramic Society has greatly assisted to this end. Our output capacity has reached over 600,000 per month, but averages just under half a million per month.

"A paper contributed recently by M.M. Le Chatelier and Bogitch the well-known French authorities, goes a long way towards proving that bricks can be made from Greek magnesite which are physically stronger at high temperature than the Styrian bricks, and show greater resistance to load under temperatures in excess of 1,400° C.

"I am doing all I can to encourage a scheme which has taken definite shape for the economical handling and much more methodical treatment of the mineral, coupled with a system of distribution which should result in the supply to all steelworks of a better product at the lowest cost.

"We are very backward still in regard to the scientific manufacture of silica, fire, and coke oven bricks. There is a great field for exploration: Dr. Mellor and The Ceramic Society have done much good work in this direction, as have also Professors Cobb and Fearnsides, Dr. Scott and others; but we have a long way yet to go before we solve the larger problems which are set us.

"At the meeting of the Ceramic Society held in Glasgow last October much time was given to the discussion of silica bricks, their manufacture, and behaviour in the furnace. It was made abundantly clear that this subject, in which the Sheffield steel industry is so directly interested, was engaging the careful study of many of our leading scientists, and that there were many problems still to be solved. It was made evident also that much improvement remained to be effected in the manufacture and the burning. It is well to study the refractory properties of silica bricks; the estimation of the proportions of quartz, tridymite, or cristobalite in silica bricks; the application of the petrographic methods to the study of silica bricks; the thermal or reversible expansion of silica bricks, their behaviour under load, etc., etc.; but if these scientific contributions are not applied to the manufacture, and every advantage taken of the knowledge so acquired, by improving in every process of actual manufacture, then the good work of the scientist is lost, at any rate in a large measure.

"Both before and since the war began I have visited many silica brickworks in the country, and the crude methods of manufacture which continue to be applied in most instances have caused me a feeling of disappointment. There has not been exhibited that keen desire to produce a brick superior to anything hitherto made. There has been an absence of care in selecting the best stone, in washing it free from foreign matter or overburden; the grinding has not been even and regular; the lime used for the bond

has not been exactly determined or maintained; the mixing has been uneven; the texture of the bricks has varied; the moulding and setting have not received the attention they deserve; but above all the burning has been irregular and more or less by rule of thumb, or by the "eye" as the foreman would say, all factors contributing to the common failures of spalling or slagging. I hope my friends will not think I am "rounding" upon them unduly. I believe they know how much I am interested in their welfare and progress.

"I have felt time and time again how much remained to be done in the way of improvement in firing the kilns, and what potential economies existed in coal consumption if only gaseous firing was introduced, based on scientifically constructed gas producers, and with kilns arranged so as to burn the hot producer gas with preheated secondary air under perfect regulation, and to employ usefully the waste heat of combustion in addition. I am satisfied that the coal bills of the brickmakers could be 'cut' enormously if scientific knowledge was more generally applied both in regard to the construction and the working of their kilns and the full utilization of the heat of the waste gases, in addition to which a better and more reliable product would be secured.

"Nor are these remarks confined to silica bricks alone, they apply with equal force to other refractories. I feel satisfied that the manufacturers will find themselves compelled to scrap their antiquated kilns when the days of keen competition return, if they desire to maintain their place in the industry. This subject has received already the attention of foreigners, as is indicated by the number of patent kilns introduced during recent years into this country, and all bearing names which may be said to be un-English.

"It may interest you to learn that the average output of refractories for munition purposes, resolved into terms of bricks, is about 60 millions per month, or a tonnage of nearly 200,000 per month.

"The South Yorkshire coal deposits are of inestimable value to the district and the country—their splendid coking qualities are almost unrivalled. Therefore the development of by-product recovery coke ovens is of great and immediate interest to you. There is a great field of usefulness to be explored here, in the direction of obtaining coke oven bricks which will stand up much better to their work than hitherto. Interesting chemical and physical problems are involved, affording ample food for assimilation by our scientific men,

and equally wide scope for our refractory material makers.

"I feel confident that the solution of our coke oven troubles lies in the direction of the production of high quality bricks with oven walls made from straight ganister as free as possible from deleterious impurities, burnt in the kilns to higher temperatures and for longer periods than usual, so as to enable the coke ovens themselves to be worked at considerably higher temperatures than the present practice.

"This may seem in a measure contrary to the views of some of my friends present, especially in regard to the coking of salty coals such as we have in South Yorkshire and Derbyshire; but my own experience in connection with the carbonisation of salty coals in horizontal and vertical gas retorts unquestionably points in this direction.

"I make no pretence to being a scientist—I have recognised at all times the value of the scientist's views and have endeavoured to work along the lines indicated by him, and the opinion I have just ventured to express is the outcome of so working, combined with observation, and very expensive experience.

"The electric furnace which interests the Sheffield steelmakers so greatly, and the adoption of which has been recently—and will be in the future—much extended opens up a wide field for scientific investigations as regards the refractory linings and also the electrodes used. At present neither are satisfactory, and the efficiency of the furnaces taken over a period is lamentably low—much can be done to improve in the directions indicated. The normal working conditions in an electric furnace are more exacting than in the open hearth furnace, and compel the provision of far better refractory linings than are at present available, and the solution of the difficulties would appear to be in the direction of refractory materials better made and far better shrunk or burnt, as the case may be.

"The utilization of the 'higher' refractories—such, for example, as zirconia—in electric furnaces is another subject for scientific investigation. Believing, as I do, that research work will disclose the extreme value of zirconia when purified and properly adapted for use in the linings of electric furnaces, I have arranged considerable shipments to this country of this mineral by the Ministry of Munitions—I fear we are far behind the Germans in the scientific use of this material.

"Considerable progress, however, has been made in the purification of this ore, and I have here a sample of

practically pure zirconium oxide which has been produced by a process that may be said to be a sound commercial proposition.

"Much useful work lies ahead of us in the direction of research work upon refractories at higher temperatures than those presently recognised as the normal working limits. The tendency is always upward in regard to heat treatment. Consequently, the demands upon manufacturers of refractories must of necessity be more exacting and compel the exercise of greater care in every stage of production and of burning.

"In these and all kindred matters The Ceramic Society can and will readily assist, and manufacturers should gladly avail themselves of the opportunities of assistance which the Society affords.

"You are all acquainted with what is known as the Whitley Report, on the relations between employers and employees, and the suggested formation of Joint Standing Industrial Councils. It is a gratifying incident that the scheme suggested in this Whitley Report has been first carried into effect by the employers of the refractories industry.

"The closer the relations between employers and workers the better the results for all concerned. Many and great difficulties lie immediately ahead. The demobilization of our Army at the termination of the terrible conflict in which we are still engaged will in itself create great trouble if not carefully handled, especially in those trades which have had to expand to meet war requirements, notwithstanding the withdrawal of many of their regular workers who enlisted at the outset of the war or have been called upon to serve from time to time. The return of these brave men to civil employment, coupled with the restoration of their Trade Union rules, will give rise to difficulties of a grave nature if proper provision is not exercised. Many of them will demand re-employment in their old vocations, and under improved conditions, and to my mind they will be fully entitled to every consideration, after all the sacrifices they have made and the dangers they have endured.

"It is important, therefore, that the recommendations made by the Whitley Committee should be carefully studied and extended, seeing that the refractories industry has accepted the broad principle laid down, and this can be done by forming Joint District Councils and Works' Committees. The closer the relations between employers and employees the better the understanding, and the better

the understanding the less likelihood of local disputes. Eliminate local disputes and the grounds for general strikes disappear.

"I would certainly hope that the spirit which has animated American employers and workmen's Trade Unions to agree that there shall be no strikes or lock-outs during the war might be extended alike in its scope, and to peace times. If it is possible in war time it should be possible in peace times also.

"The employers of this country should strive always at having contented workpeople about them—to get into closer touch with them through the members of their Joint Works' Committee—to immediately tackle any real grievance in a proper spirit; generally to act upon the broad principle that by studying their workpeople's welfare they are indeed studying their own.

"The forthcoming legislation to secure compensation to workmen who may contract silicosis of the lungs and be prejudicially affected thereby owing to the nature of their employment in the ganister or silica refractories industry, coupled with a system of compulsory insurance on the part of the employers, is a step in the right direction. It was originally contemplated to apply such legislation to the ganister mining industry only, but I have done my best to get its application extended to quarrying, crushing, grinding, and sieving, as also to the setting and emptying of kilns, and handling generally of silica materials, and I understand the Home Office intend so to apply the scheme of compensation, which is fairer alike to the employers and workmen, and will tend to lighten the burden on the former while benefiting more generally the latter.

"You cannot develop efficiency unless the workpeople are happy and contented, and are participants in your prosperity in a just and fair proportion.

"I know we are very far off from the condition I have described, but it is the only satisfactory solution of the labour problem.

"Many of the difficulties between employers and employees arise from the fact that the employer has not been progressive in his methods of manufacture, and in bad times he finds himself severely handicapped, not by reason of his workpeople being inefficient, but by reason of his obsolescent or semi-obsolescent plant.

"The prosperity of this country depends upon her exports, upon her ability to compete against the other industrial nations of the world for the world's trade. There-

fore, we must be in the van of progress, and this can only be secured by enlightened methods and the possession of enlightened and contented workers.

"The Ceramic Society will gladly assist manufacturers in improving their methods of production; the employers must themselves gain the contentment of their workpeople; with such a combination secured we need have no fear as to the future.

"I would desire, before closing, to express on behalf of The Ceramic Society the debt of gratitude which the members owe to Prof. Fearnsides, Mr. Cyrus Jones, and the gentlemen who have assisted them in making the arrangements for this meeting. Everything has been most excellently carried out, and they have shown a foresight and thoroughness which have assured the success of this 'Spring Meeting,' and I am sure we are all fully appreciative of the great amount of work which they have so generously undertaken."

The Chairman read out the list of visitors and called upon Prof. Armstrong (Sheffield) to propose the toast of "Our Visitors." In rising to respond Prof. ARMSTRONG remarked:—

"Mr. President and members of The Ceramic Society, I am privileged to propose a toast which I am sure, especially after the statement you have heard descriptive of the official guests of the Society, will be heartily received. Usually when called on to propose the toast of 'The Guests,' the speaker has some difficulty in classifying them in any way, but to-night, I think, they can be arranged quite neatly under Town, Gown, The Cutlers' Company and Dr. Mellor. Gentlemen, you have already noted that the Town is represented by the Right Hon. the Lord Mayor. In addition, you have Mr. Alderman Hobson and one or two other members of the Corporation. 'Gown' is represented by the Vice-Chancellor of the University, together with quite a number of his colleagues; The Cutlers' Company by their 'Four year old Master' and by two Past Masters. Those of you who have in any way studied the history of Sheffield must be aware that this is one of the few cities in our country in which Town and Gown are united in a really effective way. In Sheffield, these two bodies were in active co-operation before the war; the war has helped to cement the union, making it stronger and more than ever determined to go forward. So much has been said of the objects of the meeting that it is unnecessary to refer to them at any

length. It is often said that bricks cannot be made without straw; it is equally certain that steel cannot be made without bricks, therefore no place can be more suitable than this town of Sheffield for the consideration of all matters relating to the supply of refractories, and you will only be too anxious to recognise how much you are indebted to your official guests.

"I have attended a good many meetings in the course of my life, but I have never been at one at which the desire on the part of all to work together was more evident. Our President has said a good deal of co-operation in industry, and the Lord Mayor also referred to the importance of co-ordinating industries. May I be allowed to interpose the hope that we shall not over-organize and allow our individuality to be set aside too entirely. I have had a pretty long experience in these matters. I was a student in Germany before the war of 1870, and have every reason to know and appreciate German ability; their wonderful discipline and power of working together, and their relative lack of individuality. We have made our position through the use of many leaders but few followers. If we had organized our individuality we should never have been in the peril we have been in during the past three years. But I see growing evidence of a desire for control, a willingness on the part of the country to submit to control, to an extent which I regard as unhealthy. It is necessary that we should organize, but do not let us overdo organization.

"Although this topic is no part of the toast, the issue is so important that I venture to point out to manufacturers that they may find that they are being 'organized' in ways of which they are scarcely aware, not to the advantage of industry.

"Science has its definite place in industry but cannot be imposed upon it; I hold that the growth must come from within. Bureaucratic control will not serve our purpose.

"It is clear that great progress has been made in Sheffield. There is active co-operation of Town and Gown, and it must, therefore, give the members of this Society the greatest pleasure to drink to the health of the representative men present at this banquet. Lastly, I come to Dr. Mellor. His services cannot be referred to too often or over-rated. He has been engaged in a particularly difficult task, in bringing a scientific atmosphere into existence in regions where the scientific atmosphere has been very rare up to the present time, in the pottery industry; and now he has taken the brick industry in hand. The colossal importance

of that industry is not quite appreciated, even among yourselves perhaps. You do not think of it sufficiently in connection with coal. I am one of those who believe that eventually the whole of the bituminous coal of the country will be coked before it is burnt, and that therefore we shall need ovens which will stand very rough usage. On this account, the work which Dr. Mellor is doing is work that we have to honour in the very highest way possible. I am privileged to couple this toast with the 'Four year old' Master of The Cutlers' Company. Not being a Sheffield man, I may not be alive to all he has done, but I know that his work has been of the greatest value and that you will need no further words from me to recommend him. I ask you to drink to the official guests of the Society, coupled primarily with the name of the Master Cutler."

The Master Cutler, Sir W. H. ELLIS, in responding, aid:—

"I have before me a list of what are called distinguished visitors, and I should like to say a word on behalf of each one, but, as that is quite impossible, I am going to make allusions to one or two names. I would like first of all to state that there appears to be some doubt as to the name of this learned Society, and, feeling it might be so, I took the trouble of consulting the Greek Lexicon and find that the word ceramic is derived from the Greek word 'Keramos.' I have been listening all the evening for someone to make a slip, but so far as I know the only one of us to make a mistake to-night is the Chairman; Mr. Chairman I would like to remind you that the C is really a Kappa. I may say that I looked this up, because when this invitation came into my hand I made the same easy mistake and was corrected.

"I want to say one word, first of all alluding to Prof. Armstrong's remark about the association between 'Town and Gown,' I would rather call it 'University and Industry.' We owe a debt that we shall never forget to the President of the Board of Education, Mr. Fisher. Although he came to Sheffield as a well-known Oxford student, with all the ideals of an old University, he at once grasped the fact that a University in a town like this is in a totally different position to that of the purely academic universities, and being a broad-minded educationist recognized the need for different treatment as regards co-ordination between science and industry.

"He came here to bring about a real feeling of co-operation, appreciating the useful work of the learning of the University and the industry of the city, and I believe that feeling is more alive to-day than ever it has been. We hope to have him back with us some time. We are aware of our limitations, we know what we may look for, and I have had evidence of the fact that the learned side of the University can only help the industrial side of the city, by getting to know us and realizing what our limitations are. In connection with replying to the various visitors, I should like to especially reply for our dear old friend Dr. Hicks, a name that will always live with honour in connection with the founding of the University of Sheffield. It was his unselfishness that assisted the founding of the University we are so proud of. I should like to reply on behalf of Mr. Hobson, but Mr. Hobson is so well able to reply for himself that I will only say that Mr. Hobson is one of your most honoured guests in having been Lord Mayor, Master Cutler, and now is Pro-Chancellor of the University. Then I must say a word for the association of the Vice-Chancellor of the University in a movement of this sort. We are proud to have someone of engineering fame, Dr. Ripper; I am quite sure that those of us who are engaged in an engineering career recognise that he has done much for the good of the city.

"I know it is very invidious to mention names, but I cannot leave out the personal thanks, or offering them on your behalf, on the part of Dr. Palmer Wynne, F.R.S., a distinguished chemist. Then you have been very wise I think in adding representatives of the press to your list of visitors, and I am sure that you wish me to express our pleasure at the presence of the two leading members of the press. It is most fortunate that we should have the press interested in such work as that done by your Society in Sheffield, and I feel sure they will be pleased to have been included in your invitation. I wish to thank you on behalf of myself. I have always carried my years pretty well, but Prof. Armstrong has put it very poetically in calling me a 'Four year old.' I want to thank you as one who has been perhaps more honoured by the confidence of various Government departments, and his fellow townsmen than any other citizen of Sheffield, and it has been my privilege to be surrounded by loyal helpers who were anxious that I should succeed if possible, and I shall look back with keen satisfaction that at a time of stress my fellow townsmen had the courage to put me in office and keep me there four years."

This was followed by a speech from Alderman A. J. HOBSON, who said:—

"Mr. President, Mr. Master Cutler and gentlemen, I noticed with some interest that although one speaker chaffed the Chairman about the Society's name he did not chaff the Society.

"The question that comes to my mind is that we here to-night are recognizing a state of affairs, that seems to me to be one of the most helpful features of the industrial life of this country.

"In the past we trusted to individual effort and traditional ways. I remember that an ancestor of mine was a member of the first Company in 1685, because his mark descended to my family, and I have in my possession the freedoms of members of my family in the Cutlers' Company for the last 200 years, and I think this shows that they believed in co-operation in the trade in which they were born. The Sheffield manufacturer is a curious individual, and there has been an amount of suspicion and jealousy which has, to some extent, come to an end, and for this result we have largely to thank a great man, the late Col. H. Hughes. Co-operation is one thing, but there is another thing, which is that we must learn to discard those things, which have handicapped us, in favour of more brains, or, in other words, of becoming more scientific. I began in a handicraft trade, and after 40 years I celebrated my connection with the firm by turning it into a limited company; but the lesson of those 40 years has been that the old ways, however good, must give way to new ways, and I have been drawn gradually from a handicraft business to a scientific business. I joined the board of William Jessop & Son in 1890, and it is a source of satisfaction to me that the first thing I did was to engage a good chemist and equip a laboratory, and from that time onwards until the Sheffield steel firms founded the refinery that is now dealing with the preparation of tungsten, my belief in chemistry has grown and grown, until in that business we have five chemists engaged in watching over the works and four more in a research laboratory, engaged in problems as to how we can improve the methods of manufacture. I can only say that these keen young men appear to have been able to do in two years what took the Germans 20, and in those two years we have overtaken the Germans in the perfection of our produce. It has been a very keen pleasure to me to be associated with the refining of tungsten in England, and

from that business we are growing out towards the perfection of various alloys that may be necessary, and the Board have very great confidence that the enterprise is only in its early days and it will grow to be a great source of strength to Sheffield. If we have been able to do something there, that will prove to be one of the great services that we have been forced to do for ourselves. I am equally prepared to believe that the researches of science in other directions will do great things for us. We spent a great deal of money at William Jessop & Sons on the investigation of electric furnaces, and in that respect we have a great deal of progress still to make. We are only in the early days of electric furnaces and the proper methods of lining them, and this still leaves a great deal for your Society to do. There are other problems as to the use of refractories and the improvement of crucibles. We are at present busy in our research laboratory at Widnes as to the right crucible for tungsten. We are devoting ourselves to the solution of that problem and hoping to solve it. I also feel that if there is one piece of public work that leaves me entirely happy it is the development of the University of Sheffield. The University has still, what shall I say, very many gaps, and I do not wish to say too much of what it has done; but it is a young and vigorous University and is not afraid to start new departments, and one department which has started recently is the department that is under Prof. W. G. Fearnsides. I believe that we have been able to do a great work for the steel trade, and it will be found after this war that we have been doing an almost equally great work for the non-ferrous metal industries. As far as the University is concerned we have already justified our existence, and I hope we shall be able to make this the premier University for training in metallurgy, and if we are able to do that we shall have done something of inestimable advantage and we can leave it to our children and grand-children to bring it to perfection.

"I feel that in the association of the University with a Society such as has met here to-night, with a keen interest in imparting knowledge and placing it at the disposal of others, there is more profit for everybody than in a jealous attitude, and therefore by stimulating the University to do its duty and give the right teaching, and in such movements as this lies the hope of the future. I am very glad to be here to-night and to bear testimony as to the value of these societies, and to look forward hopefully to the future of science in this country."

On Wednesday morning the business meeting of the Society was held, presided over by the President. The Minutes of the last meeting were read and confirmed. Dr. Mellor reported that at the Council Meeting it had been decided to increase the subscription to 25/- for ordinary members, (the subscription for firms remaining at £2 2s. per annum), and explained that the increase was necessary owing to the greatly increased cost of production of the TRANSACTIONS. It was arranged that the Autumn (1918) Meeting be held at Swansea, and the Spring (1919) Meeting be held at Middlesbrough. Following the business meeting the first report of the Committee on the Standardization of Methods of Testing was presented and accepted. Dr. R. S. Hutton read the paper, "Note on Electric Treatment of Refractories"; and Mr. W. J. Rees read "A Note on a Firebrick from the Crown of an Electric Steel Furnace." In the afternoon the members were divided into groups and visited various works, invitations having been received from Messrs. Edgar Allen & Co., Ltd., John Brown & Co., Ltd., T. Firth & Sons, Ltd., Steel, Peech & Tozer, Ltd., and Vickers, Ltd.

Mr. Cosmo Johns gave a popular public lecture in the evening on "Science and the Practical Man." Mr. F. H. Brooke (Oughtibridge) in proposing a vote of thanks to Mr. Johns, said, "I should like to congratulate Mr. Johns on his most excellent lecture, which has been most interesting from beginning to end. Mr. Johns has mentioned Faraday, and I was pleased because he was a Yorkshireman, born in the village of Clapham, near Settle, and there is to-day the name Faraday over the chemist's shop in the village." Mr. Bernard Moore seconded the vote of thanks.

Dr. MELLOR brought a very successful meeting to an end by expressing his appreciation of Mr. John's lecture, and said: "I cannot leave this building without expressing my own personal feelings, and I believe the feelings of my fellow members of The Ceramic Society, at the great welcome and warm hospitality we have received in Sheffield. We greatly appreciate what you have done, and thank you most sincerely. The local committee, the local secretaries—Prof. Fearnsides and Mr. Cyrus Jones—have made such excellent arrangements that the whole proceedings covering two days' hard work have passed smoothly and well, without a hitch. You have given us so grand a welcome that we are looking forward to coming back again. I also feel that we have had a brilliant finish to our proceedings in Mr. John's lecture, and I am pleased to have the chance of

recording my appreciation of his remarks. I am glad Mr. Johns did not mention aniline dyes, because I am not sure that the developments were not due to A. W. Hofmann, who came from Germany, and after working in London for a time returned to Berlin.

ERRATUM.

The translation on p. 94, Vol. 14, was by Prof. H. B. Dixon, This was inadvertently omitted in the footnote.

On the title page of Vol. 15 of the TRANSACTIONS the volume is stated as "Volume XIV—Session 1915-16." This should read "Volume XV—Session 1915-16."

Vol. 15, p. 77, for 2·32 read 2·28 for specific gravity of α-Tridymite.

Vol. 15, p. 78, fifth line from bottom, for 575° or 580° read 870°.

Vol. 16, p. 202. The remarks in the second paragraph of the discussion on Mr. Timmis' paper were not made by Mr. G. W. Mottram; we are unable to trace the author.

Add to the list of papers read at the Leeds meeting indicated in the Proceedings, p. 333, Vol. 16, "The Dressler Kiln," by Mr. C. Dressler.

Present Vol., p. 188, last line but one in footnote, for "ability" read "utility."

Second line from bottom page 121, transpose "greatest" and "least."

W. J. JONES, Esq.,

President for Session 1917-18.

TRANSACTIONS

OF

THE CERAMIC SOCIETY

INCLUDING

THE REFRACTORY MATERIALS SECTION.

Founded in 1900 as "The North Staffordshire Ceramic Society," and continued from 1903 to 1916 as "The English Ceramic Society."

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1918.

I.—Sur les propriétés réfractaires de la Silice.

par MM. H. Le Chatelier et B. Bogitch.

L'EMPLOI des briques de silice dans la construction des fours a seul permis la généralisation du chauffage à chaleur régénérée de W. Siemens. Avec les briques d'argile, les voûtes ne pouvaient supporter les températures ainsi obtenues et s'effondraient rapidement. Jusqu'ici ce pendant, on n'a pas expliqué d'une façon certaine cette supériorité de la silice sur l'argile.

Nos expériences récentes sur les propriétés réfractaires de l'argile[1] permettent au contraire d'entrevoir une explication très précise. Les briques d'argile, comme nous l'avons établi, commencent à se ramollir entre 1,300° et 1,400°. Elles ne peuvent plus alors supporter d'efforts importants sans céder d'une façon continue et indéfinie Elles le font d'autant plus rapidement que la température est plus élevée, c'est à dire, elles se comportent comme une matière vitreuse, elles n'ont pas de véritable point de fusion, mais seulement un palier très étendu de fusibilité. Le prétendu point de fusion de la kaolinite pure, fixé à 1,780° et identique à celui du quartz, déterminé de la même façon par l'emploi de montres de Seger, correspond en réalité à l'affaissement rapide de la matière sous une charge égale au poids même de l'éprouvette, c'est à dire de l'ordre de 1 gramme par cm². Sous une charge 10,000 fois plus forte, c'est à dire de 10 kilogs. par cm² l'affaissement du kaolin se produit avec la même vitesse, 400° plus bas.

Pour expliquer la façon différente de se comporter de l'argile et du quartz, on pouvait supposer que ce dernier présentait au contraire un véritable point de fusion, sans ramollissement préalable, indépendant par suite de la pression. Nos expériences ont pleinement confirme cette prévision. Quand on écrase vers 1,500° un petit cylindre d'argile, on le voit gonfler en forme de tonneau, puis s'aplatir en une galette à bords arrondis, sans présenter à aucun moment de rupture proprement dite. Après refroidissement, la masse écrasée a conserve toute sa dureté premiére. Au contraire, avec la silice,

1) C. R, CLXIV, 904, 1917.

la première action de la pression ne produit aucun effet appréciable. Mais en l'augmentant progressivement, on voit brusquement l'éprouvette se briser, en présentant les deux cônes de glissement que l'on observe dans la rupture par compression de toutes les matières dures. Les fragments brisés ne se ressoudent aucunement pendant le refroidissement. L'effort nécessaire pour produire cette rupture brusque décroit progressivement avec l'élévation de la température.

Le tableau et la courbe (Fig. 1) ci contre résument les résultats de nos expériences sur une bonne brique de silice de fabrication Américaine, marque "Star." Les résistances à l'écrasement sont exprimés en kilogs par cm^2.

Température		Résistance
15°	..	170
520°	..	158
670°	..	150
800°	..	139
950°	..	125
1050°	..	120
1200°	..	85
1320°	..	62
1460°	..	50
1540°	..	37
1600°	..	30

Ces nombres conduisent par extrapolation à une résistance de 12 kilogs à 1,700°, température habituelle des voûtes de fours d'aciéries. Cette résistance correspond à peu près à dix fois l'effort que les briques supportent dans les voûtes. La stabilité de ces dernières est donc assurée.

Cette résistance mécanique se conservant jusqu'à des températures élevées est une particularité toute spéciale aux briques de silice. On ne la retrouve pas, non seulement dans les briques d'argile, mais même dans les briques de magnésie, dont le constituant essentiel, la magnésie, est cependant bien moins fusible encore que la silice.

Voici la raison de ces différences. Dans les deux cas, les briques renferment des oxydes basiques étrangers à la matière réfractaire principale. Ces oxydes: Alumine, chaux, oxyde de fer, alcalis, etc., donnent dans tous les cas naissance à une matière fusible, déja liquide aux environs de 1,200°. Dans le cas de la magnésie, les grains solides de ce corps nagent dans le magma fondu et glissent facilement les uns sur les autres comme le ferait du sable mouillé. La silice au contraire, du moins dans les briques bien cuites, forme un réseau continu dans les pores duquel se loge la masse fondue, comme l'eau se loge dans les pores de la pierre ponce, sans en diminuer la résistance mécanique. La formation de ce réseau, conséquence de la recristallisation de la silice, est due, comme l'un de nous l'a

fait voir,[1] aux différences de solubilité des différentes variétés allotropiques de la silice. Le quartz, instable à haute température, se dissout dans le magma fondu et recristallise à l'état de cristobalite d'abord, puis de tridymite (Fig. 2). Cette recristallisation de la silice et par suite le formation du réseau indéformable, exigent une cuisson effectuée à une température convenable et suffisamment prolongée. Les briques peu cuites, dont le réseau n'est pas encore formé, sont composées de grains de quartz nageant dans la masse fondue; elles sont plastiques, comme les briques de magnésie ou d'argile. C'est là un fait bien connu dans les usines; les briques peu cuites sont fusibles et inutilisables.

Lorsque l'on chauffe une bonne brique de silice, sa résistance diminue cependant avec l'élévation de la température. Cela tien à ce que la solubilité de la silice croissant avec la température, il se produit une dissolution progressive du réseau cristallin tendant à le désagréger et même, à le disloquer complètement. Cet effet sera d'autant plus retardé que le réseau sera mieux développé. C'est de là que dépend avant tout la qualite des briques de silice. L'étude des facteurs dont dépend la rigidité de ce réseau présente donc une importance de premier ordre. Les recherches dont nous rendons compte aujourd'hui ont pour objet d'éclaircir ce problème.

Les principaux facteurs à envisager sont:
La proportion des fondants.
La température actuelle de la brique.
La bonne formation du réseau.
La désagrégation du réseau par gonflement ultérieur.

Proportion des oxydes fondants. Nous avons analysé quelques briques qui nous avaient été signalées comme ayant donné des résultats particulièrement satisfaisants à l'emploi. Le tableau ci dessous donne le poids p. cent. des oxydes basiques, ainsi que le poids total des sulfates obtenus par une attaque à l'acide fluorhydrique, suivie d'une évaporation à sec après addition d'acide sulfurique:

Marque	Al_2O_3	Fe_2O_3	CaO	MgO et K_2O	Total	Sulfates
Star	0·94	0·15	1·79	0·50	3·38	9·06
Assailly	2·72	1·30	0·20	0·25	4·47	13·60
G. I.	1·02	0·60	1·48	0 00	3·10	8·40

(1) H. Le Chatelier, *Rev. de Mettallurgie, XIII.*, 330, 1917.

La brique Star est celle dont la résistance a été donnée plus haut. La brique d'Assailly, dont la fabrication remonte à 30 ans, avait séjourné un an dans la paroi d'unconduit de gaz d'un four d'aciérie. C'est sur cet échantillon que l'un de nous(1) a reconnu pour la première fois la transformation du quartz en tridymite dans les briques longtemps chauffées. Enfin la brique G.I. est une brique de fabrication française, passant pour une des meilleures de celles que nous produisons actuellement.

D'après ces chiffres les bonnes briques de silice renferment entre 3 et 5 p. cent. d'oxydes basiques et le poids des sulfates varie de 8 à 14 p. cent. Le rapport du poids des oxydes à celui des sulfates varie nécessairement suivant la nature des bases. Mais comme leurs proportions relatives restent généralement comprises entre des limites assez reserrées, on peut admettre que le poids des oxydes représente une fraction sensiblement constante du poids des sulfates, soit en moyenne 35 p. cent. Ce dosage des sulfates peut être fait rapidement et suffit pour apprécier la composition d'une brique de silice.

Température. La température que supporte la brique dépend entièrement de l'usage auquel elle est destinée. Dans les fours à acier, elle doit supporter une température de 1,700°. Les briques présentant la composition cidessus indiquée, possèdent, si elles ont été bien fabriquées, une résistance suffisante à la température en question. On emploie encore les briques de silice dans les fours à distiller la houille, où la température est moins élevée. On peut sans inconvénient accepter pour cet usage une proportion au moins double des oxydes basiques, ce qui facilite grandement la fabrication.

Constitution du réseau. C'est là la partie la plus délicate de la fabrication. Pour développer le réseau, il faut maintenir très longtemps la brique à une température où le magma fondu soit suffisamment fluide. L'expérience semble indiquer, comme conditions les plus favorables, un chauffage prolongé plusieurs jours à une température voisine de 1,450°. Cette température doit être inférieure à celle à laquelle le quartz employé se transforme directement et rapidement en cristobalite. Le réseau se forme exclusivement aux dépens des parties de silice qui recristallisent par dissolution passagère dans la masse fondue. Enfin cette recristallisation sera d'autant plus complète et plus rapide, toute chose égale d'ailleurs, qu'il y aura dans le mélange soumis à la cuisson plus de quartz fin et même très fin. Il faut cependant une certaine proportion de gros grains pour empêcher la formation de fentes dont la propagation se fait trop facilement dans les matière uniformément fines.

(1) H. Le Chatelier, C.R., CXI, 123, 1890.

Désagrégation du réseau. Lorsqu'il reste après cuisson des grains de quartz non transformés et que l'on chauffe ensuite brusquement la brique à une température à laquelle le quartz se transforme rapidement, le gonflement qui accompagne cette transformation brise le réseau et enlève toute solidité à la brique. De plus, la pression qu'elle supporte dans la voûte s'oppose à son gonflement latéral et produit le phénomène *d'écaillage*; elle tombe alors par petits morceaux, entraînant parfois en quelques jours la destruction d'une voûte qui aurait dû faire des mois de service. La photographie ci contre (Fig. 3) montre une brique semblable avant et après mise en place dans le four. On voit très nettement les fentes provoquées par ce gonflement. Ce défaut est peut être le plus grave et certainement le plus fréquent de ceux que présentent les mauvaises briques de silice. Dans la fabrication normale d'une brique bien cuite, le même gonflement se produit au moment de la transformation directe des gros grains de quartz qui ne se dissolvent jamais que sur une très faible épaisseur, mais l'inconvénient n'est pas le même, par ce qu'alors le gonflement de la brique peut se développer librement dans tous les sens et que d'autre part le phénomène est assez lent pour permettre au réseau de se reformer sur les points ou il a pu être brisé. Néammoins ce phènomène inévitable diminue notablement la résistance mécanique de la brique.

Voici maintenant le détail des expériences qui ont conduit aux conclusions précédemment énoncées. Elles ont porté sur des briques qui nous ont été fournies par les usines de la Marine, fonderie de cannons de Ruelle et fabrique de blindages de Guérigny, et pour lesquelles on nous a donné l'indication des qualités à l'emploi. Nous avons mesuré la proportion des sulfates, les densités absolues et apparentes la résistance à l'écrasement en kilogs par cm^2 à des températures déterminées et après un temps de chauffage également donné.

Marques	Qualité	Sulfates	D. Absolue	D. Apparente	Résistance		
					Température	Temps	R
Assailly	T. Bonne	13·6%	2·30	1·92	15°		550
					1600°	60′	90
Star ..	T. Bonne	9·06%	2·33	1·66	15°		170
					1600°	5′	33
					Id	60′	30
G.I. ..	T. Bonne	8 40%	2·33	1·88	15°		185
					1600°	60′	41
R.B. ..	T. Bonne	13·1%	2 35	1·60	15°		62
					1600°	60′	9·5
R.L. ..	T. Bonne	14·3%	2·40	1·85	15°		265
					1600°	5′	41
					Id	60′	25
G.A. ..	Bonne	14·0%	2·40	1·77	15°		190
					1600°	60′	21
D. ..	Bonne	8·4%	2·45	1·73	15°		320
					1600°	5′	55
					Id	60′	20
G.A.I.	T. Mauvaise	14·5%	2·46	1·80	15°		252
					1600°	60′	4·4
R.F. ..	T. Bonne	13·7%	2·48	1·84	15°		195
					1600°		11
G.A.2 ..	T. Mauvaise	12·8%	2 48	1·78	15°		148
					1600°	60′	5
G.M. ..	Médiocre	9·5%	2·53	1·84	15°		84
					1600°	5′	17
					Id	60′	2
R.L. ..	Mauvaise (éclate)	9·75%	2·56	1·94	15°		350
					1600°	5′	18
					Id	60′	4·5
R.S.G.	Mauvaise (fond)	25·0%	2·56	1·73	15°		57
					1550°	60″	22
					1600°		fondue

Ces résultats permettent de formuler une conclusion pratique très précise. Toutes les bonnes briques ont à 1,600°, après une heure de chauffage, une résistance à l'écrasement au moins égale à 10 kil. par cm². La prolongation du chauffage à cette température diminue peu leur résistance, à l'inverse de ce qui se produit pour les mauvaises briques.

DISCUSSION.

M. Henry Le Chatelier est très heureux d'avoir provoqué par sa communication une discussion aussi complète ;

il est sur presque tous les points d'accord avec les auteurs des observations faites.

Peut-être n'est-il pas nécessaire de poursuivre de nouvelles recherches sur la densité des diverses variétés de silice, aux températures élevées, comme le demande le Dr. Scott. On peut, en effet, les calculer très exactement en partant des densités mesurées à la température ordinaire et utilisant les coefficients de dilatation. On trouve ainsi que la cristobalite possède vers 1,000°, une densité voisine de 2·22. Il reconnait au contraire la difficulté de déterminer quantitativement les proportions de tridymite et de cristobalite et, plus encore l'impossibilité d'obtenir la transformation complète du quartz en tridymite, dans la première cuisson des briques. Cette transformation demande des semaines pour s'achever dans le four à acier, où la température est cependant bien plus élevée.

Le Professeur Fearnsides signale un fait tout à fait exact au sujet de la transformation première du quartz en cristobalite sous l'action de la chaleur. Après les échauffements de peu de durée, suivis d'un refroidissement rapide, on n'observe jamais que de la cristobalite. Ainsi, dans la paroi d'une cornue Bessemer, on trouve de beaux cristaux de cristobalite ; mais pas ou peu de tridymite, parce que les chauffages sont peu prolongés et les refroidissements rapides. Ces conditions sont toutes différentes de celles du four Siemens, où la température est maintenue presque constamment très élevée. C'est alors seulement que la tridymite se développe régulièrement.

A la question posée par Mr. G. W. Mottram, au sujet de la calcédoine (flint), on peut répondre que cette variété de silice se transforme comme le quartz, d'abord en cristobalite, mais elle le fait à une température très basse, à partir de 1,150°, bien avant le commencement de la fusion de silicates. En l'absence de liant, le gonflement devient énorme et la brique très poreuse perd toute résistance. Il ne semble pas que jusqu'ici on ait réussi à fabriquer de bonnes briques de silice en employant exclusivement de la calcédoine.

Il n'est évidemment pas impossible d'employer directement des briques en silico-calcaire à faible teneur en chaux, à condition de conduire très doucement l'échauffement du four, de façon à faire sur place, la cuisson de la brique. Mais il est douteux que cette pratique soit avantageuse, parce que, si les parties les plus chauffées cuisent bien, les portions intermédiaires de la brique, celles qui supportent des températures comprises entre 500° et 1,200°, perdent toute solidité et sont alors sujettes à se désagréger sous l'action des mouvements inévitables dùs à la dilatation des parois chauffées.

La question de savoir si l'on peut remplacer les grains anguleux d'une roche de quartz broyé, per du sable en grains ronds, demande encore de nouvelles études. Des essais en cours, faits avec un mélange de 75 per cent. de sable de Fontainebleau et 25 per cent. de silice impalpable, passée au tube broyeur, ont donné des résultats encourgeants.

Mr. J. Holland proteste avec beaucoup de raison contre l'idée de chercher à fabriquer des briques de silice entièrement transformées en tridymite. L'auteur du mémoire n'a jamais soutenu une semblable opinion. Cela serait absolument irréalisable, puisqu'il faut pour cette transformation un séjour de 1 mois dans un four d'aciérie à une température supérieure à 1,600°, quand les plus fortes cuissons industrielles des briques de silice, n'atteignent pas 1,400°, et que la cuisson à la température la plus élevée ne dure souvent que quelpues heures, jamais plus de quelpues jours. Il semble nécessaire d'obtenir cependant une proportion suffisante de tridymite, ce à quoi on peut arriver par l'introduction dans la pàte d'une proportion suffisante de quartz impalpable, c'est-à-dire traversant le tamis de 4·900 mailles au cm^2.

L'indication donnée par Mr. Cecil Desch au sujet de la fusibilité de la silice demanderait à ètre discutée de très près. Les diverses variétés de silice: quartz, cristobalite et tridymite ont nécessairement des points de fusion différents, la tridymite fondant à la température la plus élevée. Il semble difficile d'admettre que son point de fusion puisse s'abaisser jusqu'à 1,625°. On ne l'observe mème pas à 1,700°. On voit bien dans les vieilles briques complètement transformées en tridymite et chauffées à cette température, une partie de la masse devenir vitreuse par dissolution d'une certaine quantité de tridymite dans les silicates métalliques; mais les grains de tridymite, dans les parties respectées par le fondant restent absolument inaltérées comme structure et dimensions des cristaux. On cite parfois aussi pour le point de fusion de la variété quartz, un point de fusion de 1,480°. Ce chiffre ne parait pas davantage établi sur des bases précises. Il est probable que le point de fusion de la tridymite, ou si l'on préfère, son passage à l'état amorphe est voisin de 1,800°.

Mr. A. Lindsay Forster a décrit avec beaucoup de précision les apparences successives d'une mème brique de silice examinée dans des régions de plus en plus éloignées de la portion chauffée. La voûte des fours d'aciérie est généralement impregnée, sur la partie inférieure, de scories ferrugineuses et c'est dans cette région que les cristaux de tridymite sont le plus complètement développés.

Mr. W. Donald est effrayé du poids des données scientifiques sous lesquelles on veut écraser les fabricants de briques de silice. Sans contester aucunement les résultats auxquels sont arrivés ces fabricants par une longue expérience, s'étendant sur plusieurs générations, il sera permis de faire remarquer que, en l'absence de cette expérience pratique, les cherches de laboratoires arrivent, par leurs études scientifiques, à produire après quelques mois de travail, d'aussi bonnes briques que celles dont la mise au point, par les méthodes purement empiriques, a demandé de longues années de tàtonnements. C'est bien là, le but essentiel des méthodes scientifiques de travail. Quant aux différences signalées entre les briques d'Ecosse et de Sheffield, il serait sans doute facile d'en reconnaitre rapidement la cause, si l'on avait en mains les échantillons à comparer. Il n'est nullement prouvé que, pour avoir de bonnes briques, il faille employer des roches d'une nature spéciale. Les études faites jusqu'ici montrent, au contraire, qu'avec tous les quartz d'une dureté suffisante, et ne se pulvérisant pas au feu, il est possible, et mème facile, de faire de bonnes briques à condition d'employer une cuisson approprié à chaque nature de pierre.

Les explication de Mr. Mellor montrent très nettement quel est le but des études scientifiques et comment on peut les traduire pour les rendre accessibles aux fabricants. Peut-àtre, cependant, n'a-t-il pas assez insisté sur une particularité de grande importance. L'une des variétés de silice, à faible densité, présente une propriété très curieuse ; mais aussi très nuisible. Elle éprouve vers 225° un changement brusque de dimensions qui amène des ruptures, quand on chauffe trop rapidement les briques. On ne saurait assez recommander aux métallurgistes de mettre très lentement en feu les fours construits en briques de silice. Faute de cette précaution, on s'expose à ruiner, dès les premiers moments du chauffage, des fours construits avec des briques excellentes à tous les autres points de vue.

En ce qui concerne l'affirmation de Mr. Fenner, que la tridymite cesse d'ètre stable aux températures les plus élevées des fours, on peut dire que la pratique journalière des fours d'aciérie l'a depuis longtemps contredite. Les parties les plus chauffées des briques, primitivement composées d'un mélange de quartz et de cristobalite avec trés peu de tridymite, se transforment progressivement et d'une façon complète en cette dernière variété de silice. L'expérience est d'ailleurs très simple à réaliser au laboratoire. Il suffit de prendre une brique presque complètement à l'état de cristobalite et de la chauffer pendant quelques heures à 1,700°, pour provoquer un

développement abondant de tridymite, et cela, sans aucune des alternatives de chauffage et de refroidissement auxquelles Mr. Fenner fait allusion. Ses expériences personnelles n'ont jamais donné la preuve du contraire. Elles sont certainement très exactes, mais ont été mal interprètées par leur auteur. En chauffant, à une température élevée, de la tridymite, en présence d'un fondant, et refroidissant lentement la masse, on y trouve certainement de la cristobalite, mème de la cristobalite très bien cristallisée, comme j'en ai donné de nombreux exemples. Mais cette tridymite ne s'est pas produite à chaud; elle a cristallisé pendant le refroidissement, en se séparant du magma fondu dans lequel un excès de silice s'est dissout, grâce à l'élévation de la température. Toutes les fois que l'on refroidit avec une vitesse moyenne, un merre très chargé de silice, la première variété qui cristallise est la cristobalite. De mème, si l'on chauffe de l'iodure rouge de mercure dans l'alcool bouillant, c'est à dire bien audessous du point de transformation de l'iodure dans sa variété jaune, et que l'on refroidisse ensuite la solution, on produit toujours la variété jaune. On n'en conclut pas que le point de transformation, de l'iodure rouge en iodure jaune, est audessous du point d'ébullition de l'alcool. Il correspond, en réalité, à la température de 125°. Il en exactement de mème avec la cristobalite. Pour rendre l'expérience de Mr. Fenner concluante, il eut fallu tremper l'échantillon, après le chauffage, pour empècher toute cristallisation nouvelle de silice, au refroidissement.

[TRANSLATION.]

THE use of silica bricks, in the construction of furnaces, has alone permitted the generalisation of firing with the regeneration of heat. With clay bricks the arches could not bear the temperatures thus obtained and would give way in a very short time. Up to now, however, the superiority of silica over clay has not been explained in any certain manner.

Our recent experiments, concerning the refractory properties of clay (1) allow us, on the contrary, to perceive a very precise explanation. The clay bricks, as we have proved, begin to soften between 1,300° and 1,400°. They cannot, henceforth,

(1) *Compt. Rend.*, **164**, 904, 1917.

sustain important efforts without giving way in a continuous and indefinite manner. And this occurs more rapidly as the temperature is higher, that is to say, they act like a vitreous substance; they have no real fusing point but only an extensive fusibility range. The assumed point of fusion of pure kaolinite, fixed at 1,780° and identical with that of quartz, determined in the same way by the use of Seger cones, corresponds in reality to the rapid giving way of the substance under a load equal to the weight of the test piece, that is to say, of the order of one gram per cm.^{2} Under a load 10,000 times greater, that is to say, 10 kilos per cm^2, the giving way of kaolin is produced with the same rapidity 400° lower.

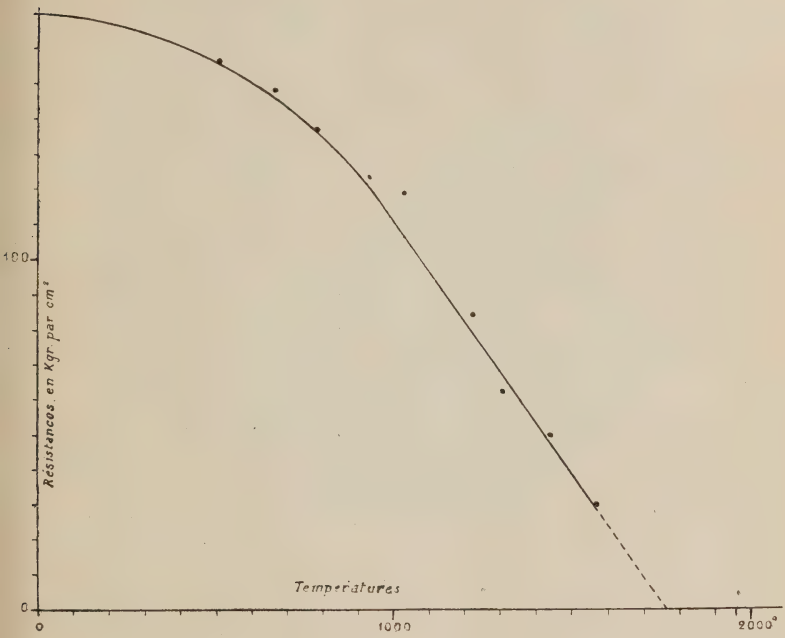

Fig. 1.

In order to explain the different way in which clay and quartz act. one could suppose that. the latter has, on the contrary, a real point of fusion, without previous softening, and consequently independent of pressure. Our experiments have fully confirmed this prevision. When, towards 1,500°, a small cylinder of clay is crushed, it can be seen dilating into barrel shape, then completely flattening out into a thin cake

with rounded edges without showing at any moment fracture properly so called. When cooled the crushed mass preserved entirely its former hardness. On the contrary, in the case of silica, the first operation of the pressure produces no appreciable effect, but, in increasing it gradually, the test piece breaks abruptly, showing the two sliding cones which are observed in all hard materials, when breaking under compression. The broken fragments do not reunite at all during the cooling. The effort necessary to produce this abrupt breakage decreases gradually with rise of temperature. The table and the curve here annexed (Fig. 1) give a summary of the results of our experiments on a good silica brick of American make, marked "Star." The resistances to crushing are expressed in kilogs. per cm²—Table I.

TABLE I.

Temperature Degrees		Resistance to Crushing
15	..	170
520	..	158
670	..	150
800	..	139
950	..	125
1050	..	120
1200	..	85
1320	..	62
1460	..	50
1540	..	37
1600	..	30

These numbers lead by extrapolation to a resistance of 12 kil. at 1,700°, the usual temperature of the arches in steel furnaces. This resistance corresponds to about 10 times the effort sustained by the bricks in the arches. Consequently, the stability of the latter is assured. This mechanical resistance, being retained up to very high temperatures, is a special peculiarity of silica bricks. It is not found, not only in clay bricks, but even in bricks whose essential constituent is magnesia, which is much less fusible still than silica. Here is the reason of these differences. In both cases the bricks contain basic oxides foreign to the principal refractory material. These oxides, alumina, lime, oxide of iron, alkalies, etc., produce in all cases a fusible matter already liquid towards 1,200°. In the case of magnesia the solid grains float in the melted magma and slip easily one over another as wet sand would do.

Silica, on the contrary, at least in well-fired bricks, forms a continuous network in the pores of which the melted mass

lodges, like water lodges in the pores of pumice-stone without diminishing the mechanical resistance. The formation of this network, in consequence of the recrystallization of the silica, is due, as one of us has proved(1) to the differences of solubility of the different allotropic varieties of silica. The quartz, unstable at high temperature, dissolves in the melted magma and recrystallizes first of all as cristobalite then as tridymite (Fig. 2).

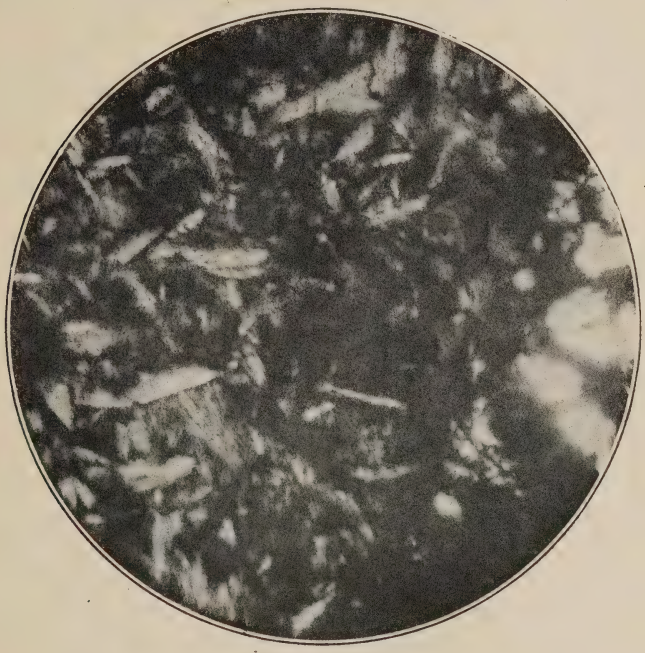

Fig. 2.—Showing a network of tridymite in a silica brick very well fired. Polarised light x 200.

This recrystallization of silica and subsequently the formation of the permanent network, require firing sufficiently prolonged at a suitable temperature.

Bricks little fired, whose network is not yet formed, are composed of grains of quartz, floating in the melted mass; they are plastic like the magnesia bricks or the clay bricks. It is a fact well known in the manufactories that bricks little fired are fusible and useless.

(1) H. Le Chatelier, *Revue de Métallurgie*, **13**, 330, 1917.

When a good silica brick is heated, its resistance diminishes with rise of temperature. The reason of this is that the solubility of silica, increasing with the temperature, a progressive dissolution of the crystalline network is produced and tends to disintegrate it and even to dislocate it entirely. This effect is the more delayed as the network is better developed. It is on this that the quality of silica bricks depends before anything else. To study the factors on which the rigidity of this network depends is consequently a study of the first importance.

The researches of which we give an account to-day have for their object the solution of this problem. The principal factors to take into consideration are:

The proportion of fluxes.

The actual temperature of the brick.

The good formation of the network.

The disintegration of the network through subsequent swelling out.

Proportion of fluxes. We have analysed some bricks which had been pointed out to us as having given particularly good practical results. The table below gives the weight per cent. of the basic oxides as well as the total weight of the sulphates obtained by an attack of hydrofluoric acid followed by evaporation to dryness after addition of sulphuric acid.

TABLE II.

Mark	Al_2O_3	Fe_2O_3	CaO	MgO & K_2O	Total	Sulphates
Star	0·94	0·15	1·79	0·50	3·38	9·06
Assailly	2·72	1·30	0·20	0·25	4·47	13·60
G. I.	1·02	0·60	1·48	0·00	3·10	8·40

The "Star" brick is the one whose resistance has been given as the highest. The "Assailly" brick, the manufacture of which goes back 30 years, had remained a year in the wall of a gas channel belonging to a steel furnace. It is on this sample that one of us(1) recognised for the first time the trans-

(1) Le Chatelier, *Compt. Rend.*, **111**, 123, 1890.

formation of quartz into tridymite in bricks which have been heated for a long time. Finally, the brick "G.I." is a brick of French manufacture, considered as one of the best amongst those actually manufactured by the French.

According to the above figures, good silica bricks contain between 3 and 5 per cent. of basic oxides, and the weight of sulphates varies from 8 to 14 per cent. The relation between the weight of the oxides and those of the sulphates varies necessarily according to the nature of the bases, but, as their relative proportions remain generally confined between fairly close limits, it can be said that the weights of the oxides represent a practically constant fraction of the weights of the sulphates, let us say, on an average of 35 per cent. This proportion of ingredients in sulphates can be made rapidly and suffices to estimate the composition of a silica brick.

Temperature. The temperature which the brick supports depends entirely on the use one wishes to make of it. In steel furnaces it must bear a temperature of 1,700°. Bricks offering the composition shown above possess, if they have been well manufactured, sufficient resistance to the temperature mentioned. Silica bricks are also used in ovens for the distillation of coal, in which the temperature is not so high. A proportion, at least double of the basic oxides, can be used without inconvenience for this purpose, and thus the manufacture is made much easier.

Constitution of the network. This is the most delicate part of the manufacture. In order to develop the network the brick must be kept for a very long time at such a high temperature that the melted magma may be sufficiently fluid. Experience seems to indicate, as the most favorable conditions, several days' firing at a temperature approaching 1,450°. This temperature must be inferior to that at which the quartz used is directly and rapidly transformed into cristobalite. The network is formed exclusively at the expense of the portions of silica which recrystallize through momentary dissolution into the melted mass. Finally this recrystallization will be accomplished the more completely and rapidly, everything being otherwise equal, if the quartz used in the fired mixture is fine or even very fine. However, a certain proportion of large grains is necessary to prevent the formation of cracks, whose propagation happens easily when the material is uniformly fine.

Disintegration of the network. When, after firing, grains of quartz remain not transformed, if the brick is afterwards

abruptly heated to a temperature at which quartz is rapidly transformed, the expansion which accompanies this transformation shatters the network and robs the brick of all solidity. Moreover, the pressure to which it is submitted in the arch resists its lateral expansion and produces the phenomenon of spalling; thus it falls in small fragments, causing sometimes, in a few days, the destruction of an arch which should have lasted months. The reproduced photograph (Fig. 3) shows a similar brick before and after being placed in the furnace. The cracks caused by this expansion are easily seen. The defect is perhaps the gravest and certainly the most frequent of those which affect bad silica bricks.

In the normal manufacture of a well-fired brick, the same expansion is produced at the time of the direct transformation

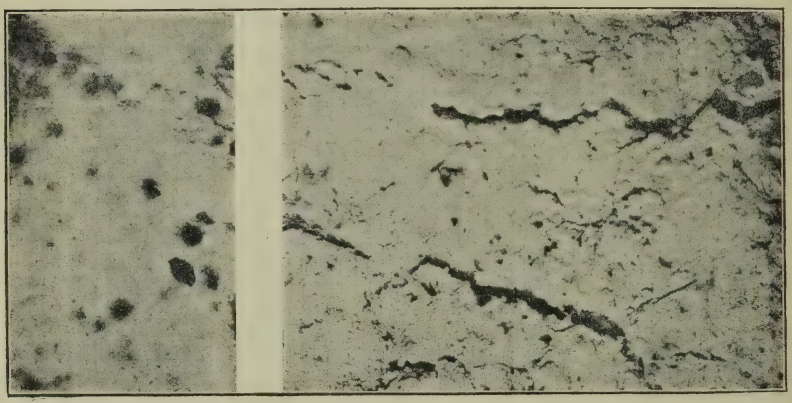

Fig. 3.—Showing insufficiently fired brick, spalling by rapid heating in a steel furnace.

of the large grains of quartz, which never dissolve except on the surface; but the inconvenience is not the same, because then the expansion of the brick can develop itself freely in all directions, and, on the other hand, the phenomenon is slow enough to permit the network to reform itself on the places where it has been cracked. Nevertheless, this unavoidable phenomenon diminishes notably the mechanical resistance of the brick.

Here are now the details of the experiments which have led to the conclusions previously expressed. They refer to bricks which have been handed to us by the manufactories of the

Navy, by the Ruelle foundry of guns and the Guérigny manufacture of armour-plating and for which they have given us the indication of qualities in use. We have measured the proportion of sulphates, the apparent and absolute densities, and the resistance to crushing in kilogs. per cm² measured at definite temperatures and after a definite time of firing. The results are shown in Table III.

TABLE III.

Marks	Quality	Sulphates Per Cent.	Absolute Density	Apparent Density	Resistance to Crushing		
					Temperature	Time	Crushing Strength
					Degrees		
Assailly	Very good	13·6	2·30	1·92	15		550
					1600	60′	90
Star ..	Very good	9·06	2·33	1·66	15		170
					1600	5′	33
					Id	60′	30
G.I. ..	Very good	8·40	2·33	1·88	15		185
					1600	60′	41
R.B. ..	Very good	13·1	2·35	1·60	15		62
					1600	60′	9·5
R.L. ..	Very good	14·3	2·40	1·85	15		265
					1600	5′	41
					Id	60′	25
G.A. ..	Good	14·0	2·40	1·77	15		190
					1600	60′	21
D. ..	Good	8·4	2·45	1·73	15		320
					1600	5′	55
					Id	60′	20
G.A.I.	Very bad	14·5	2·46	1·80	15		252
					1600	60′	4·4
R.F. ..	Very good	13·7	2·48	1·84	15		195
					1600		11
G.A. 2..	Very bad	12·8	2·48	1·78	15		148
					1600	60′	5
G.M. ..	Medium	9·5	2·53	1·84	15		84
					1600	5′	17
					Id	60′	2
R.L. ..	Bad (cracked)	9·75	2·56	1·94	15		350
					1600	5′	18
					Id	60′	4·5
R.S.G.	Bad (melts)	25·0	2·56	1·73	15		57
					1550	60′	22
					1600	melted	

These results allow us to formulate a very precise and practical conclusion. All good bricks possess at 1,600°, after heating for an hour, a resistance to crushing at least equal to 10 kil. per cm^2. The prolongation of heating, at this temperature, diminishes their resistance little in opposition to what happens with bad bricks.

DISCUSSION.

Dr. A. SCOTT (Glasgow):—When Fenner published his paper on the "Silica Minerals" some years ago, most people came to the conclusion that almost the last word had been spoken on the subject. According to Fenner α-quartz is the stable form up to 575°, β-quartz from 575° to 870°, tridymite from 870° to 1,470°, and cristobalite above 1,470°. The last named, however, may develop as an unstable intermediate phase below 1,470°. Recently, however, M. Le Chatelier has shown that the stability relations, particularly of tridymite and cristobalite, are still in doubt, as not only has he found tridymite in bricks which had been exposed for a long time at about 1,500° but he was also unable to convert tridymite to cristobalite by heating to 1,700°. Recently I have had occasion to examine a number of silica bricks which had been for many months at a temperature of over 1,500°, and my results confirm those of M. Le Chatelier. The hottest parts of the brick were entirely tridymite, but cristobalite mixed with tridymite appeared some distance from the hot end, while towards the cool end the number of partly converted unaltered quartz grains increased. This points to the conclusion that under certain conditions tridymite is stable above 1,500°.

This question is not merely an academic one but is of considerable technical importance on account of the volume changes which accompany the polymorphic transformations. Unfortunately the data we have regarding the physical properties of the various modifications are meagre and to a certain extent contradictory. Most text books on refractories, for example, give the specific gravities of the α-forms but are silent regarding the β or high temperature forms, which are perhaps the more important from the technical point of view. According to M. Le Chatelier, the transformation in the case of cristobalite is accompanied by a large volume change, while in the case of quartz and tridymite the volume change is much less. Fenner, on the other hand, states that the energy changes in the α-β transformations are very slight, which is scarcely

consistent with a large volume change. What is really wanted is a revision of the determinations of the densities of the high temperature forms, but this is a problem involving considerable experimental difficulties.

The discrimination of cristobalite and tridymite is another point which may involve some difficulty, as, while in some cases it is possible to discriminate between the two by crystal habit, in others the only certain method is by means of the refractive indices. Although the refractive indices of the two minerals are near to each other, it is possible to discriminate between them by the immersion method, working under constant temperature conditions. The double refraction is of little use in distinguishing the two minerals. Recently quantitative estimations of the Rosiwal method of the various constituents present in silica bricks have been made, but it seems very doubtful if these possess any high degree of accuracy. The Rosiwal method is very useful in the case of igneous rocks which are comparatively coarse-grained, but where the grain size is small the measurements are of little value. In the case of silica bricks the grain size of the cristobalite and tridymite is small, these minerals are difficult to discriminate, and the presence of the bond introduces further complications, so that the Rosiwal method seems scarcely applicable.

With regard to unused bricks, it is often stated that they contain considerable quantities of tridymite or cristobalite—the two terms seem to be often regarded as interchangeable in this country—but, so far as my examinations have gone, neither form is present to any great extent in unused bricks. Under the microscope an unused brick shows that most of the quartz is still unaltered. It is only after repeated heating at a high temperature that the isolated quartz grains are converted, and even then the ganister fragments are only altered round their margins, while only after very prolonged use at a high temperature is anything like complete conversion obtained.

It seems to me that if anyone can find a method whereby the quartz can be converted to tridymite during the firing in the kiln many troubles will disappear, as the chief expansion will then occur before the brick is built into a furnace. This expansion, which occurs during the first few weeks of use, is of great importance, and in certain cases is greater than what theoretically would be expected from data we have concerning the densities of the various forms.

Professor FEARNSIDES (Sheffield):—In opening this discussion, Dr. Scott has made reference to a good many of the difficulties encountered by those of us who have endeavoured to interpret and apply to actual works conditions the information which has been published from the Geo-Physical Laboratory at Washington, respecting the phase-changes or transformations undergone by silica when heated, and, in following him, I should like to add my testimony to his appreciation of the immediate practical applicability of the results which M. Le Chatelier, whom we regard as the doyen of European phase-rule workers, has contributed to the available information upon this important subject.

With regard to the question whether tridymite or cristobalite represents the highest temperature phase, it is noteworthy that when molten steel is run into a mould built up of quartz-sand mixed with aluminous or ferruginous clay bond, the silica grains in the burnt skin of the mould, after the casting has cooled, are invariably found with a pellicle of cristobalite surrounding each cracked quartz-grain. I have looked for, but have not succeeded in finding, any development of tridymite in association with the sand which is so burnt by contact with steel castings, and which must have been raised instantaneously to temperatures between 1,500° and 1,600° C.

The idea introduced by M. Le Chatelier in this and in his earlier paper contributed to the *Revue de Métallurgie*, vol. 13, 1917, that tridymite is most conveniently formed from quartz by the intervention of some silicate flux or solvent, in which the quartz, at temperatures above the range of its true stability is dissolved, and out of which, when the solution becomes saturated with silica at that same temperature (which is within the stability range of tridymite), the tridymite can crystallise, is a very useful and acceptable working hypothesis. Almost a year ago, when describing "The Supplies of Refractory Materials available in the South Yorkshire Coalfield," and dealing more particularly with the siliceous seat-earth of the Halifax Hard Bed Coal of the Sheffield district, I ventured to attribute the quick-burning properties of true ganister to the presence of "some small quantity of impurity which behaves as a catalytic agent, and 'triggers off' the change from quartz into tridymite at temperatures comparatively low."[1] That use of the term "catalytic agent" has met with a good deal of adverse criticism, and I would like to

1 Trans. Inst. Min. Eng., vol. lii., p 270.

take this opportunity to acknowledge that my choice of term was not very happy, though as a matter of fact my conclusions and those arrived at by M. Le Chatelier are quite compatible.

I can confirm M. Le Chatelier's contention that the transformation change of the quartz particles into tridymite during the burning works invariably inwards from the outside of the grain, and with him I agree that it is of considerable importance that tridymite as a mineral crystallizes in the hexagonal (or pseudo-hexagonal) system, and generally forms in rods, which, in growing, tend to elongate themselves into needles, and so build up a skeletal network which is sufficiently rigid at high temperatures to support considerable stress. In this respect tridymite differs from cristobalite, which seems to belong to the cubic system, and when it crystallizes forms equi-dimensional grains, which, when associated with the melt, which is generally rather viscous, slide over one another with comparative ease.

My experience of the proportion of tridymite contained in silica bricks as generally sent out by the makers for use in steel furnaces is quite in accordance with what Dr. Scott has told us, and I have yet to find a brand of silica bricks in which the proportion of unaltered quartz averages less than 60 per cent. In many silica bricks, which have actually been in use in the arches of steel furnaces for a period which may have extended over many months, it is unusual to meet with specimens in which the whole of the quartz has been inverted, either into tridymite or into cristobalite.

Mr. G. W. Mottram:—In nearly all research work on silica the starting point is either quartz, or quartzite, and this paper is no exception to the rule.

Very little is heard in any discussion on silica about the amorphous, or semi-amorphous forms, such as the various kinds of flint.

It would be interesting to learn what changes—if any—are effected in these forms of silica by heat treatment; whether there are changes to tridymite, or cristobalite, as in the case of quartz.

The calcination of flint, as pebbles, gives quite a different result as compared with the calcination of stratified flint.

While it is generally admitted that the burning of silica bricks should be carried to the inversion point so as to form tridymite, or cristobalite, and that only angular grains of silica should be used, one can hear of good results where these

conditions have been absent in the manufacture. A short time ago I had a specimen silica brick, which had been made on the sand-lime brick principle, with $1\frac{3}{4}$ per cent. lime, presumably from sand with rounded grains, and hardened by steam. These bricks had not been burned, so we must assume that there was no change to tridymite, at any rate by ordinary heating. A number of these bricks were built in the wall of an open-hearth furnace, and the temperature gradually raised. The result was that they proved quite as durable and satisfactory as the standard quality silica bricks, made in the usual way, from Sheffield ganister. According to the usual theories these bricks should have changed to tridymite, or cristobalite, while in the furnace wall, and the resulting expansion should have shattered them.

It would almost seem as if the theory of the inversion points and the necessity for angular grains in the manufacture of silica bricks need further investigation.

Mr. J. G. ROBERTS (Barrhead):—There are one or two points which have been overlooked in this discussion:—

H. Le Chatelier makes one observation of very great importance, that is: That the density of cristobalite, tridymite, and vitreous silica are the same at 1,000° C. This is a point of great practical importance in the use of silica brick.

The greatest change in volume appears to take place during the transformation of quartz to cristobalite, and if this change has largely taken place then at high temperatures there should be little difficulty over undue expansion of the silica. We certainly want a good deal of the volume change brought about before the bricks are put into use.

Prof. Fearnsides referred to the transformation of quartz into cristobalite, and to a brick the portion of which nearest the heat zone consisted of cristobalite with tridymite further back. This does not agree with Le Chatelier's observation, who says that he took a brick which had been in a steel furnace and found it to consist entirely of tridymite. He tried to transform this into cristobalite but failed.

Le Chatelier appears to regard tridymite as the stable high temperature form of silica.

Mr. B. MOORE:—Calcined bone enters largely into the composition of English porcelain, attempts have been made to replace it with precipitated phosphates but they have been failures, the ware would not stand in the oven although the

chemical composition was the same. The shape of the particles seems to have an important bearing on the practical results and confirm the views of the author of the paper.

Mr. J. HOLLAND (Sheffield):—I think Professor Le Chatelier's valuable paper is beyond criticism. We probably all agree on the main points, but on the question of the conversion of silica, if it is agreed that the ideal brick would be composed of tridymite, I do not think there is a single brickmaker who could not, if he tried, make a tridymite brick (probably at an excessive cost)—but could he get anyone to buy it? In silica bricks, as at present made, there is a certain amount of tridymite brought about in the ordinary course of manufacture, and every practical furnace builder, from experience, knows exactly how much to allow for expansion in building his furnace. There is no difficulty at all about this point. He does not worry about the conversion of the silica, but simply makes his expansion joints.

It seems to me to be a commercial question, whether we continue to make a silica brick at a comparatively low price, or are we to attempt to make tridymite bricks, for which probably no one would pay the price? Do we really need a tridymite brick? Is it necessary we should have them? If we take a silica brick which has been a long time in use in the furnace we find the end nearest the fire is cristobalite, and the tridymite follows after that, merging in the partly unconverted silica portion towards the outside end.

The present silica brick, in a properly regulated steel works, is so well understood by steel works managers, that they know exactly what to do with it. I do not know that if a furnace was built of tridymite brick it would last for an indefinite time, and as a brick manufacturer I have no desire to see a brick that will last for ever.

I am particularly interested in those drawings made by Professor Fearnsides—on the blackboard—arising out of one of the questions as to the difference in structure between ganister rock and silica sandstone. They typify the difference as we understand it in Sheffield.

The ganister stone, when ground—no matter to what degree of fineness—breaks with very irregular cleavage and sharp edges, and each particle is—what I call for want of a better term—prismatic in formation, so that when the heat is applied, and the conversion of the silica commences, these particles have a tendency to knit closely together, and thus form a mechanically strong brick.

There is a great difference in silica sandstone, which some people consider and describe as ganister. This stone, when broken and ground, is of a sandy character, and the small particles are round, so that, when conversion takes place, the particles have not that tendency to knit together that we find in ganister. I do not think that anything should be called ganister, unless it appromixates both chemically and physically to that mineral which has always been known as ganister.

In the first place, chemically: If the material is chemically bad there is an end of it; but if it be chemically good it does not follow that it would prove good in use unless it is also physically good.

Ganister, as we know it in Sheffield, is both chemically and physically good.

Fortunately, it is not too pure chemically, but contains a proportion of impurities which appear to be of great value in its application to industry. Its physical condition is ideal, and I repeat that only material approximating to these two conditions should be classed as ganister.

Mr. Arthur Acton, at our last meeting, made a suggestion that I think is one to which further consideration should be given, viz.: to classify material as:

1. Ganister.
2. Quartzite or Dinas type rocks.

And I would suggest a third: silica sandstone, and probably other types might be added. All these materials are of great industrial value, and, if the various rocks could be classified, and named as they most nearly approach a standard type, I think it would be a step in the right direction.

Dr. Cecil H. Desch (Glasgow) said that the paper presented many points of great scientific interest, and it was gratifying that Prof. Le Chatelier, to whom we owed some of the earliest scientific investigations on this subject, had within the last few years again turned his attention to it, with results of great importance. It seemed desirable (perhaps the Ceramic Society had already considered the matter) that some general agreement should be reached as to the temperature which was to be regarded as characteristic of a refractory, in respect to its softening by heat. The Geo-Physical Laboratory, in accordance with physico-chemical theory, considered the melting point to be the temperature at which the crystalline structure was destroyed, and the substance passed into the amorphous condition. This was strictly correct, but had practical disadvantages. For instance, the melting point of silica was about

1,625° C., but the amorphous material formed at that temperature had a rigidity comparable with that of the solid, and one was met by the paradox that a steel furnace, built of bricks supposed to melt at 1,625° C., would be in regular use at temperatures considerably above that. A definition of the softening point, as distinguished from the melting point, would seem to be desirable.

The paper appeared to point to the advantage of firing at as high a temperature as possible. The fact that all the cementing materials used in making a silica brick had a softening effect suggested the possibility of eliminating them altogether. In the case of certain of the newer refractories he understood that it was possible to make a brick by binding particles of the highly-fired material with a paste of the same material in a plastic unfired condition. Could not this plan be applied to silica? Fragmentary silica, fired at so high a temperature as to have undergone inversion, might be bound by means of silica in a colloidal form. This was only a suggestion, which might perhaps be practicable.

Prof. Fearnsides' observation as to the effect of molten steel on sand in the foundry was not quite conclusive as to the relative stability of tridymite and cristobalite. The time of contact in such a case was short, and sufficient time was not allowed for equilibrium to be attained. Now, if a substance could exist in several polymorphic modifications, it did not necessarily follow that at any given temperature the new phase first formed would be that which was stable at that temperature. In fact, the contrary was frequently the case, and there was a rule, often found to hold good in physical chemistry, that the phase to be formed was not the most stable, but that next below it in stability, further inversion only taking place after a much longer time. This, of course, did not dispose of Prof. Fearnsides' argument, but made it uncertain whether any conclusion could be drawn, without extending the heating over a long period.

Mr. A. LINDSAY FORSTER (Glasgow):—One or two features connected with some silica bricks used by us may be of interest to the meeting. They were examined by Dr. Scott, who pointed out to me that the end of the brick which had been exposed to the furnace temperature was entirely tridymite, while the portion next to it was a mixture of tridymite and cristobalite, the outer cool end being almost entirely quartz. The brick might be considered as comprising three portions, that at the hot end being almost sharply distinguishable from the centre portion: it measured, say, half an inch,

and was white and very "dry." These bricks had been in use for about 12 months at a furnace heat that was nothing extraordinary. They had "expanded" considerably, and the process of growth had continued for quite a long time.

If one knew how much "expansion" is to be allowed for with a particular kind or batch of bricks the user would be in a much more satisfactory position, but precise and reliable information on this point is not readily obtainable from makers as a rule.

Mr. Wm. Donald (Glasgow):—Mr. President, I would like to add some remarks to the subject as one who in the past manufactured silica bricks. With certain reservations, that I will make later, one might say that this is a branch of refractories that as a trade is being introduced to Scotland, at any rate its discussion is, and those present who have no knowledge of the manufacture of silica bricks must have been rather appalled, and those who have actually made them, looking at the subject from their practical point of view, must have been better able to understand the very learned discussions that have been put forward by Monsieur Le Chatelier, Dr. Desch, Professor Fearnsides and Dr. Scott. If they were to start with such highly abstruse scientific discussions to guide them I am afraid that silica brick manufacturers would feel they had a terrible load on their shoulders, and it is for that reason that I would like to add some practical suggestions.

In the forenoon we had a discussion about ganisters, and there was an attempt made to define what true ganisters are, one speaker suggesting that the name "ganister brick" should be limited to those bricks made in the neighbourhood of Sheffield from the Sheffield ganisters, and from other deposits clearly recognised by geologists to be from similar geological formations. I am certain that the Sheffield makers present will agree with me that from the various deposits available in the neighbourhood of Sheffield you could manufacture half a dozen qualities of silica bricks. You could make them of greater or less porosity, for instance. The trade is longest established in Sheffield, and it is for that reason I take it as standard. In the past it is true that the silica bricks made there were made from the finest deposits available. These naturally good deposits made bricks with certain qualities. The manufacture was begun on very simple lines at a time when the demand was not so urgent as it has been recently. Whatever plant was available was allowed to do its work in its own time so as to produce what in the course of years was found to be a good saleable article for furnace purposes. Generations

followed each other in sixty years or so, and certain improvements had been devised throughout several periods of that time as the stress of passing circumstances quickened the minds of those taking part in the manufacture; but it was hard for outsiders to notice much change. One good thing was that the quality remained on a sufficiently high level. The tremendous expansion of the trade during the past three years made it necessary for the miners and searchers to go further and further afield for new deposits of material to make the increased requirements of silica bricks of that quality. But the desired quality of the finished article was well known to all the workers employed at each stage of manufacture, and especially known to those who had the acceptance or refusal of the raw materials, and only those have been accepted that the existing plant could deal satisfactorily with.

The great expansion of the steel trade in Scotland, and the necessity to limit the railway traffic makes it desirable that an effort should be made to extend the trade more fully in Scotland. Already in more recent years there has been a well-established trade that produces a silica brick well known as suitable for special purposes in steel furnaces and coke ovens for instance, but which is easily recognised to be very different from those of Sheffield and South Wales. What is the difference? And why should other districts like those of the northern counties of England have their productions as clearly able to be recognised as having specific qualities and yet that makers should not be able to get results from their bricks exactly comparable to those obtained in the most trying parts of the furnaces by the Sheffield and Welsh makers? Why should the North Wales silica bricks differ from the South Wales bricks, and what are those differences? One very practical suggestion is to compare the physical characteristics such as weight and porosity of the best bricks able to be manufactured from the various deposits, making sure that the cubic contents is always the same. I remember doing this in the past before the war, and I found that bricks of exactly 100 cubic inches made by Sheffield makers weighed 56 cwts. per thousand at least; those by makers in the more northern counties weighed 52 cwts, per thousand, and those made at that time in Scotland from Scottish deposits of silica not more than 50 cwts. per thousand. In each case the analysis was practically the same, but there was a variation of porosity.

Let the definition of the raw silica material to be found in Scotland be ganister, silica stone or whatever its local name is, the quality of the deposits most desired—and we must ask our Geological Survey to find them—is that they must have

high specific gravity without too much expansion, so that the bricks manufactured from them will have the substance of the Sheffield silica bricks.

In the manufacture of silica goods, where heat affects the dominant oxide and causes expansion with the increase of temperature, and contraction with falling temperatures, there must, I think, be a certain amount of porosity. It would be interesting to know from Dr. Desch if he has found that silica bricks completely transformed into tridymite or cristobalite remain unaltered with the variations of temperature that are experienced in open-hearth furnace parts. I have never seen such bricks, and until they have been proved to be more valuable than those that are allowed to undergo the transformation after their manufacture during steel furnace practice, I think the manufacturer may meantime take it that some porosity is essential to allow for the expansion. One factor that the users must consider, for instance, is that with expansion you can tighten the brickwork joints of a furnace in a way that is impossible under other circumstances, and that is a factor of great importance. With regard to this question of porosity we used to manufacture one quality of silica bricks which was so porous that it was of great value for fettling purposes, being able to be introduced with tongs direct into the furnace walls without disruption.

Used in the chequers these bricks could stand the constant heating and cooling, and after being six or eight months in use be taken out with long tongs, thrown on the ground, and to the extent of 50 or 60 per cent. be afterwards selected and rebuilt into the chequers again. These bricks, weighing 49 cwts. per thousand for size 100 cubic inches, had not the powers of sustaining the greatest loads and stresses in the most trying parts of the furnace that silica bricks have, that have greater substance and less porosity.

In the manufacture of silica bricks there must be purity, but, of greater importance still, there must be resistance to crushing strain under high temperatures, and, in the light of present day practice, there must, I think, be porosity.

Dr. J. W. MELLOR (communicated 10th Oct., 1917):—I have been greatly interested in the discussion which followed the reading of Monsieur le Chatelier's valuable paper. The equilibrium conditions of the many different forms of silica is an extremely important question and I do not suppose anyone realises this more than myself. I can also appreciate the position or attitude of the essentially practical man who will consider the report of this discussion to be possibly of academic

interest, but may be bewildered with the array of the alpha and beta forms of quartz, tridymite, and cristobalite, as well as amorphous silica. He will want to know in plain language what it all means, so that if there is any useful practical application he can immediately get the subject in hand, because, after all has been said, it remains for the firebrick manufacturer to transform the theory into practical rules. I have been asked to translate our somewhat academic discussion on silica bricks into plain language. My explanation runs something like this: The protean forms of crystalline silica can be ranged in two classes: ordinary silica with a high, and well-fired silica with a low specific gravity. Weight for weight, the low specific gravity forms have the greater volume. We can call the high specific gravity forms *A*-quartz, and the low specific gravity form *B*-quartz. There are two important low specific gravity forms called tridymite and cristobalite, and the differences of opinion do not necessarily mean that one advocate is right and another wrong, but rather that the mechanism of the passage from the high to the low specific gravity form is not yet clearly understood. Mere assertion is not proof. It is clear that the high specific gravity silica slowly passes into the low specific gravity form at a high temperature. If the conversion is complete the bricks may expand up to about 12 per cent. We are satisfied that it is necessary for the firebrick manufacturer to burn his silica bricks at a high enough temperature, and for a long enough time to transform the greater proportion of the raw *A*-quartz into the less dense *B*-form. The manufacturer will, of course, say that this statement lacks novelty. At present the discussion is focussing attention on the importance of this subject, and those who like clear ideas want definite answers to the questions such as these: How far is it advisable for the firebrick manufacturer to attempt to carry out the transformation? Is there a general rule, or must each variety of silica be treated independently? The former question must be answered by the user, the latter by the manufacturer; but before these and other questions can be satisfactorily answered, it is for the academies to learn the exact mechanism of changes from one form of silica to the other. We therefore welcome academic discussions as a means to a definite end.

Mr C. N. FENNER (Washington, D.C.):—The paper "On the Refractory Properties of Silica," by MM. Le Chatelier and Bogitch, and the discussion by Professor Fearnsides and Dr. Scott, have reached me at a time when the demands by the Government for certain technical products required for

military purposes have compelled me to lay aside research work and devote all my time and energies to meet these requirements. This and the fact that I am so situated at present that no references are available compel me to limit my contribution to the discussion to a few lines only.

Dr. Scott has kindly referred to my work on the silica minerals,[1] but his remarks indicate that some of the conditions which affect the attainment of stability, on which I laid emphasis, were not fully in his mind at the time he wrote. The fact mentioned by him that tridymite is found in bricks which have been exposed to a temperature of over 1,500° is, I believe, not at all contradictory of my conclusions, but is quite consistent with the extraordinary sluggishness of inversion which I found to be manifested as a general feature of the silica minerals and to which I directed especial attention. In such bricks as he speaks of it is very generally the case that we find not only tridymite but also quartz associated with the cristobalite which is present. Of course no one will assert that all three minerals are stable at the same time, and reflection should indicate to us that the conditions for determining stability relations are not of the best when we expose silica bricks (of somewhat variable composition, especially as regards the percentage of fluxing binder) to the fluctuating temperature conditions found in furnaces in manufacturing plants.

Several investigators, working on silica refractories, have confirmed my conclusions, and before serious question of their correctness is raised I think that evidence should be brought out that either the principles on which I based these conclusions do not apply or that the results which I described cannot be obtained by others. Of course in any experimental work of this kind all the conditions should be carefully controlled.

Professor Fearnsides makes mention in his discussion of an idea which he attributes to M. Le Chatelier "that tridymite is most conveniently formed from quartz by the intervention of some silicate flux or solvent, in which the quartz, at temperatures above the range of its true stability is dissolved, and out of which, when the solution becomes saturated with silica at that same temperature (which is within the stability range of tridymite) the tridymite can crystallize." Anyone interested may find this matter gone into rather fully in my paper.

I can hardly agree with Dr. Scott's opinion that there should be a parallelism between the magnitude of the energy-change and that of the volume-change involved in transformation.

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1 The Stability Relations of the Silica Minerals, *Amer. Journ. Sci.*, xxxvi., 331-384, Oct., 1913.

M. H. Le CHATELIER:—I am very pleased my paper has provoked such thorough discussion. On nearly all points I am in agreement with the previous speakers.

Perhaps it may not be necessary to pursue fresh researches on the densities of the different varieties of silica at high temperatures, as Dr. Scott desires. They can indeed be calculated very accurately from the densities measured at ordinary temperature, using the coefficients of expansion. In this way it is found that cristobalite possesses a density towards 1,000° bordering on 2·22. The difficulty of determining quantitatively the proportions of tridymite and cristobalite, and still more the impossibility of obtaining complete transformation of the quartz into tridymite in the first firing of the bricks, is acknowledged.

This transformation requires weeks to finish it in a steel furnace, where the temperature is much more elevated.

Prof. Fearnsides points out quite correctly a fact in the subject of the first transformation of quartz into cristobalite under the action of heat. After heatings of short duration, followed by rapid cooling, cristobalite only is always observed. Thus fine crystals of cristobalite are found in the wall of a Bessemer converter, but little or no tridymite, because the firings are so little prolonged and the coolings rapid. These conditions are all different from those of the Siemens furnace, where the temperature is maintained very high almost constantly It is only then that tridymite is regularly developed

As to Mr. Mottram's question concerning flint, this variety of silica is transformed, like quartz, first into cristobalite, but it is effected at a very low temperature, from 1,150°, well before fusion of the silicates begins. In the absence of binding material, the swelling becomes enormous and the very porous brick loses all resistance. It does not seem that good silica bricks have bene made successfully hitherto by using flint exclusively.

It is obviously not impossible to employ directly sand-lime bricks with small content in lime, on condition of conducting slowly the heating of the furnace, in such a manner as to fire the brick in its place. But it is questionable whether this practice is advantageous, because if the parts most heated are well fired, the intervening portions of the brick, which support temperatures between 500° and 1,200°, lose all stability and are then liable to disintegrate under the operation of the inevitable movements due to expansion of the heated walls.

The question of knowing if the angular grains of a ground quartz rock can be replaced by round grains of sand requires fresh study. Trials made with a mixture of 75 per cent. of

Fontainebleau sand and 25 per cent. impalpable silica, passed by a tube mill, have given encouraging results.

Mr. J. Holland protests with good reason against the notion of seeking to make bricks of silica transformed completely into tridymite. The author of the paper has never countenanced such an opinion. It would be absolutely unrealizable, since for this transformation a stay of one month in a steel furnace at a temperature above 1,600° would be necessary, although the most powerful industrial firings of silica bricks reaches only 1,400, and firing at the highest temperature often last only a few hours, never more than a few days. Yet it seems necessary to obtain a sufficient proportion of tridymite, that which can be reached by the introduction into the paste of a sufficient proportion of impalpable quartz, that is to say, running through a sieve of 4,900 meshes to the square cm.

The information given by Dr. Cecil Desch on the subject of the fusibility of silica will require to be discussed very closely. The different varieties of silica (quartz, cristobalite, and tridymite) necessarily have different fusion points, tridymite melting at the highest temperature. It seems difficult to admit that its fusion point can be brought down to 1,625°. It cannot be observed even at 1,700°. In old bricks completely transformed into tridymite, and heated to that temperature, a part of the mass is seen to become vitreous by solution of a certain quantity of tridymite in the metallic silicates; but the parts respected by the flux remain absolutely unaltered as to structure and dimensions of the crystals. Sometimes 1,480° is cited as the fusion point of quartz. That number appears no more established on exact bases. It is probable that the fusion point of tridymite—or, if preferred, its passage to the amorphous condition—is bordering on 1,800°.

Mr. A. Lindsay Forster has described with great accuracy the successive appearances of a silica brick examined in regions more and more distant from the heated portion. The arch of a steel furnace is generally impregnated, on the lower part, with ferruginous slags, and it is in this region that the crystals of tridymite are most completely developed.

Mr. W. Donald is terrified at the burden of scientific data under which it is intended to crush the manufacturers of silica bricks. Without in the least contesting the results to which these manufacturers have attained by a long experience, extending over several generations, it will be permitted to remark that, in the absence of that practical experience, laboratory investigations, by their scientific studies, attain to the production after a few months of work, of as good bricks as those of which the present quality, by purely empirical

methods, required long years of groping. That is the essential object of scientific methods of working. As for the differences pointed out between Scotch and Sheffield bricks, doubtless it would be easy to find out the cause quickly if samples were at hand to be compared. It is by no means proved that rocks of a special nature must be employed in order to have good bricks. Studies made hitherto show, on the contrary, that with every quartz of sufficient hardness and not reducing to powder in the fire, it is possible and even easy to make good bricks on condition of employing a firing process suited to each kind of stone.

The explanation of Dr. Mellor shows very clearly what the object of scientific studies is, and how they can be interpreted in order to render them accessible to manufacturers. Perhaps, however, he has not laid sufficient stress on one peculiarity of great importance. One of the varieties of silica, of small density, presents a very curious property, but also very injurious. It experiences about 225° an abrupt change of dimensions which brings about fractures when the bricks are heated too rapidly. It cannot be recommended too strongly to metallurgists to set the fire very slowly in furnaces constructed of silica bricks. In default of this precaution, furnaces constructed of bricks, excellent from every other point of view, are exposed to being ruined from the first moments of heating.

With regard to Mr. Fenner's assertion that tridymite ceases to be stable at the highest temperatures of the furnaces, it may be said that the daily practice of steel furnaces contradicted it long ago. The most strongly heated parts of the bricks, originally composed of a mixture of quartz and cristobalite with very little tridymite, is progressively transformed and in a complete manner into this last variety of silica. Moreover, the experiment is very simple to realize in the laboratory. It is sufficient to take a brick almost completely in the condition of cristobalite and to heat it for several hours at 1,700°, in order to promote an abundant development of tridymite, and that without any of the alternations of heating and cooling to which Mr. Fenner makes allusion. His personal experiments have never given proof to the contrary. They are certainly very exact, but have been badly interpreted by their author. On heating tridymite at a high temperature, in the presence of a flux, and cooling the mass slowly, cristobalite is certainly found, even well crystallized cristobalite, as in numerous examples I have given. But this tridymite is not produced by heat; it has crystallized during cooling, separating from the melted magma in which an excess of silica is dissolved, thanks to the elevation of the temperature. Every time that

a glass highly charged with silica is cooled with moderate speed, the first variety which crystallizes is cristobalite. So, if red iodide of mercury be heated in boiling alcohol, that is to say, well below the point of transformation of the iodide into its yellow variety, and be cooled after solution, the yellow variety is always produced. It is not concluded that the point of transformation of the red iodide into the yellow iodide is below the boiling point of alcohol. It really corresponds to the temperature of 125°. It is exactly the same with cristobalite. In order to render Mr. Fenner's experiment conclusive, the sample should have been steeped, after heating, in order to prevent all new crystallization of silica on cooling.

II.—The Distribution and Geological Position of the Valuable Fireclays and Ganisters of the South of Scotland.

By L. W. Hinxman, B.A., F.R.S.E., and M. MacGregor, M.A., B.Sc.

THE subjoined table shows the main sub-divisions of the Carboniferous System recognised in Scotland and used in the published maps of the Geological Survey :—

Upper Barren Red Measures.
Productive Coal Measures.
Millstone Grit.
Carboniferous Limestone Series.
Calciferous Sandstone Series.

Fireclays occur in each of these sub-divisions, but the chief source of the valuable refractory material in Scotland is the Millstone Grit. This has accordingly been given priority of treatment in the following paper. In later sections the fireclays and ganisters of the other sub-divisions are more briefly dealt with.

Millstone Grit.

Introduction.

The fireclays and ganisters at present used in Scotland in the manufacture of high-class refractory goods are chiefly confined to the Millstone Grit strata between Glasgow and Bonnybridge on the western side of the Central Coalfield. This localisation of the fireclay industry—more marked even than that of the oil-shales of the Lothians, though from a different cause—is primarily due to the fact that the industrial centres of the west, with their blast-furnaces, foundries, steel, glass and chemical works, have created a large and increasing market for refractory materials, both raw and manufactured. Ample supplies of suitable fireclay were fortunately found to exist in the neighbourhood of these centres, and thus, while rocks of Millstone Grit age cover considerable parts of the South of Scotland, it is only in certain limited areas that their economic possibilities have been adequately tested.

Central Coalfield.

The rocks of the Millstone Grit Series in this region form an irregular strip of varying breadth on either side of the great Coal Measure basin, whose axis extends eastwards from the Clyde above Glasgow to the neighbourhood of Slamannan and thence northwards in the direction of Alloa and Stirling. The continuity of the belt on the western side of the basin is interrupted by a series of parallel east-and-west faults of considerable magnitude. The downthrow of most of these faults is to the south, causing the outcrops of the different beds to be successively stepped back westwards, the lateral shift in some cases amounting to one or even two miles. This western belt stretches eastwards from the northern suburbs of Glasgow to Garnkirk and Glenboig and thence northwards to Castlecary, Bonnybridge and Plean: to the north of Castlecary the continuity of the outcrop is broken by the outlier of Coal Measures forming the Banknock Coalfield.

An isolated area of Millstone Grit strata is found within the City of Glasgow boundaries, occupying the districts of Garngad, Blochairn, and Germiston. Fireclay was formerly worked opencast to the east of the Blochairn Steel Works, and a pit, sunk in the near vicinity, passed through four lower seams of clay. Little is, however, known with regard to these early workings.

The Millstone Grit on the eastern side of the basin occupies a continuous strip of country stretching from the Forth, near Grangemouth, southwards to Levenseat. There it expands to form the barren upland tract of the Gladsmuir Hills and Auchterhead Muir. In connection with this main outcrop there are two north-west pitching anticlines of Millstone Grit strata which illustrate the secondary flexures into which the Central Coalfield has been thrown. One of these extends from Whitburn to near Balgornie; the other from Allanton to Salsburgh, and round both folds the lower seams of the Coal Measures can be continuously traced. Both anticlines contain refractory fireclays which are now being worked. (See Drum Pits and Hareshaw Mine below.)

On the west side of the basin the thickness of the Millstone Grit increases steadily from S.W. to N.E. Near Rutherglen, where it is overlain by Coal Measures, it is approximately 330 feet thick. To the north-east of Coatbridge is varies from 276 feet at Gartsherrie to 320 feet at Burnlip, a little way south-east of Glenboig Station.[1] Near Slamannan it is about 636 feet thick, at South Drum, Bonnybridge, approximately

[1] Memoirs of Geological Survey of Scotland, Central Coalfield of Scotland, Area V, pp. 28—30.

740 feet, and at Plean 900 to 960 feet. This increase appears to be confined to the upper part of the series, since the Cement Limestone and Lower Fireclay horizons preserve a constant distance above the base. There is consequently a corresponding increase from south to north in the amount of strata present between the top of the Millstone Grit and the Lower Fireclay; a fact to be borne in mind when estimating the depth of that horizon in different localities.

A similar decrease in thickness from north to south is found on the east side of the basin. Between Falkirk and the Carse of Kinneil the Millstone Grit is approximately 730 feet thick, between Bathgate and Armadale about 468 feet, and in the Fauldhouse and Levenseat district about 450 feet. To the south-west of Shotts at Bowhousebog it is roughly 400 feet, and at Jersey Bridge, a little south of Salsburgh, about 340 feet. It is still less in the Wishaw area and west of the Clyde, and at Larkhall and Stonehouse, is reduced by a local unconformity to a few feet.

In addition to this variation in thickness there are certain other geological factors which have to be considered in attempting to establish correlations between different districts.

(1) The Upper limit of the Millstone Grit is drawn at the Crofthead Slatyband Ironstone, a very useful and easily recognised horizon over a considerable area on the east side of the basin but only approximately determined on the west and south.

(2) The Castlecary Limestone which marks the base of the series is not always present. It is not found, for example, immediately west of Levenseat nor round the south-east and south side of the Lanarkshire Coalfield between Auchterhead Muir and Quarter. Its absence in this district is ascribed to local erosion during Millstone Grit times, making the thickness of that series a very variable quantity.

(3) Within the Millstone Grit Series itself there is only one readily recognisable index-horizon. This is the Cement Limestone, a calcareous band or "lumachelle" made up of the flattened shells of Orthotetids (probable *Derbya*). The Cement Limestone lies 40 to 70 feet above the Castlecary Limestone and forms an extremely useful index-mark for the fireclay horizon described below as the Lower Fireclay. In the higher and larger part of the series there is no index-horizon at all comparable with the Cement Limestone; so that where the base of the Coal Measures is a more or less indeterminate line, it becomes impossible to correlate closely the upper fireclays of the Millstone Grit of different areas. In place of tracing individual seams from one district to another, as can be done

with seams of coal or limestone, it is only possible to say that certain fireclay horizons occupy the same relative position in the Millstone Grit sequence.

Fireclays used in the manufacture of a wide range of refractory goods are found at two horizons in the Millstone Grit of the Central Coalfield, one near the base, and the other near the top, of that series. They are known as the Lower and Upper Fireclay horizons respectively. From the fact that the latter is well developed, and has long been worked in the Bonnybridge district, it is also widely known as the Bonnybridge Fireclay horizon.,

Lower Fireclay.

The Lower Fireclay lies a short distance, varying as a rule from 12 to 30 feet above a very persistent calcareous band, already referred to as the Cement Limestone or Cementstone. (See plate of vertical sections, Glenboig District.) This band, as stated above, is characterised by its abundant Orthotetid shells; it is generally thin, but locally reaches a thickness of nearly 3 feet, and in some places passes into a ferruginous cementstone. It is usually associated with a nodular ironstone, known and formerly worked in the Fauldhouse district as the "Curdly Ironstone." The Cement Limestone forms an invaluable index-mark for the Lower Fireclay in boring operations, both from its persistence as a horizon and for the reason that over the greater part of the Millstone Grit area it is the first limestone encountered after passing through the base of the Coal Measures. In the Plean district, however, three calcareous horizons with marine fossils are met with in boring through the Millstone Grit, the second or middle of these is correlated with the Cement Limestone. The Cementstone, as already stated, also preserves a fairly constant distance above the base of the series, independently of the total thickness of the formation.

Two seams of clay are wrought in some parts of the Glenboig field, the lower—the "white clay,"—pale lilac-grey in colour with a white streak, is separated by a bed of sandstone of varying thickness from a darker upper seam known as the "blue clay." The light-coloured clays are usually considered the best, but at the Gain workings the "blue clay" is found to possess very high refractory qualities.

The thickness of the individual seams is subject to constant variation The average measurement of the principal bed wrought in the Garnkirk-Glenboig district is from 6 to 12 feet, at Glencryan 5 feet, and at Castlecary 7 feet; the clay is, however, often greatly reduced or even pinched out altogether

by local erosion, the sandstone roof descending towards or resting upon the pavement of the seam. The quality of the clay also varies within comparatively short distances, and to obtain the best results in fireclay products requires careful selection and blending of material.

That the fireclays of the lower zone were formed under different conditions from the ordinary coal-seats or underclays found beneath coal seams is evident from their position. They do not represent land surfaces, but are intercalated with massive and often gritty sandstones, and though in a few instances a thin coal is associated with the fireclay, there is evidence to show that the thin coals of the lower part of the Millstone Grit are of sedimentary origin.

These clays seem to have been deposited as fine siliceous muds in still and probably land-locked waters, but their intercalation with coarse, false-bedded sandstones, and the local erosion of the underlying clays, points to the periodical irruption of strong currents and a return to open-water conditions.

The clay may be briefly described as a hydrous aluminium silicate with a small but varying percentage of fluxing impurities—iron, lime, magnesia and alkalies. The nature of the "clay-substance" of the Lower Fireclay of Glenboig has been the subject of some controversy, but the recent investigations of Dr. Mellor show that the dominant mineral of the clay is clayite, a colloidal form of kaolinite.[1]

The district between Garnkirk and Glenboig has for many years been an important centre of the fireclay industry. Fireclay was worked open-cast at Garnkirk for some time previous to the year 1836, when the Glenboig field was first opened up by Mr. R. Hillcoat. The output was small until 1860, but from that date increased steadily. The present Glenboig Union Fireclay Company was formed in 1882 by the amalgamation of two Glenboig firms.

The Lower Fireclay is now raised from pits at Heathfield, Gartcosh, Garnqueen, Gartliston and Glenboig; from mines along the crop at Inchnock, Gain, and Glencryan, Cumbernauld; also from pits further north at Castlecary Station, and at Stein's Works, between Castlecary and Bonnybridge.

Large areas of the Lower Fireclay still remain unexploited on the west side of the basin. A new field has lately been opened up some two miles to the N.E. of Glenboig, and the evidence afforded by recent bores and natural sections warrants the belief that a large extent of this clay is present at no

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1 "Do Fireclays contain Halloysite or Clayite,;' TRANS., vol. XVI, 1917, p. 73. See also Prof. J. W. Gregory, "The Glenboig Fireclay." *Proc. Roy. Soc., Edin.*, vol. XXX, 1910, p. 348, and Dr. J. S. Flett, "Geology of the Glasgow District," *Mem. Geol. Survey*, 1911, p. 219.

great depth from the surface in the area between the Luggie Water and the Walton Burn, and may extend northwards as far as the dolerite dyke that runs east and west a short distance south of Castlecary.

In the Plean district, north of Larbert, fireclays in the position of the Lower Seam are exposed in the Torwood Glen. Fireclays in association with a shelly cement-limestone have also been met with at depths of 40 to 100 fms. in recent bores put down at Carbrook and Rosehill, further to the north. Little is at present known as to the nature and quality of these clays, but it is not unlikely that a considerable field of valuable fireclay may reward further investigation in the Plean area.

On the eastern side of the basin there is only one place where a fireclay in the lower part of the Millstone Grit is worked. On the east bank of the River Avon, close to the viaduct on the Manuel and Bo'ness Railway and half a mile north-west of Linlithgow, a refractory clay of good quality, formerly worked on a small scale, has recently been reopened. This clay is associated with a shelly limestone a short distance above the base of the Millstone Grit and is almost certainly on the horizon of the Lower Fireclay. Further south, between Torphichen and Levenseat, fireclays and ganisters in approximately the same horizon have been proved in many bores, from some of which the Geological Survey have been able to collect samples for analyses and tests. Fireclays occur here at two horizons.

(1) A few fathoms above the Cement Limestone in the position of the Lower Fireclays of Castlecary and Glenboig. Some of the beds reach a thickness of 10 feet.

(2) Immediately above and below the same Limestone fireclays of workable thickness are recorded, especially in the Handaxwood and Levenseat district.

Upper Fireclay.

The Upper Fireclay horizon in the Bonnybridge district includes two or three seams of fireclay and one or two seams of ganister. (See plate of vertical sections.) A complete section shows:—

	ft.	in.		ft.	in.
Roof of silica rock ...					
Top fireclay	2	9	to	5	0
Coal				1	6
Irony rib				0	4
Coal					3 or 4
Top ganister... ...	2	0	to	3	0
Mid fireclay		about		5	0
Bottom ganister ...				3	0
Lower fireclay ...				2	0

COMPARATIVE VERTICAL SECTIONS OF MILLSTONE GRIT.

The total working thickness varies from 13 to 22 feet; it is wrought on the stoop and room system in two workings, the top fireclay being kept about 9 feet in advance of the rest.

The individual beds vary in quality and thickness. The top clay may be locally wanting or may be represented by two or three feet of sandstone and blaes. The coal is pyritous and may reach a thickness of two feet just east of Bonnybridge, but deteriorates when followed westwards. Below the coal the section sometimes shows:—

	ft.	in.		ft.	in.
Fireclay	3	0	to	5	0
Ganister	2	0	to	3	0
Fireclay	6	0	to	8	0

Lateral variation in a seam is not infrequent, and in the workings a fireclay may pass into a ganister or may contain lenticular masses of similar material.

To the south-west of Bathgate, at Drum Pits, Torbanehill, a variable seam of fireclay locally reaching a thickness of 8 feet is now being worked, and other fireclays are known to occur below. Here, as at Bonnybridge, the roof is formed by a thick post of a very pure sandstone (silica-rock), and at both localities experiments have been conducted with a view to using this material in the manufacture of silica bricks. The Drum Pits are the only place on the east side of the Central Coalfield where a fireclay near the top of the Millstone Grit is worked. At Hareshaw Mine, one mile to the south-west of Salsburgh, a 6 feet seam of fireclay is wrought, which occupies a position about 12 fathoms below the base of the Coal Measures.

After careful consideration of all available data it may be said that the Bonnybridge, Torbanehill and Hareshaw fireclays are approximately in the same relative position in the Millstone Grit sequence.

Fireclays on the same horizon as those of Drum and Hareshaw have been proved in numerous borings along the eastern side of the central coalfield and in the Allanton-Salsburgh anticline. The seam worked at Hareshaw is overlain by a 9-inch wild coal and underlain by 2 feet of coaly fake, and the coal and fireclay together represent a horizon which can be traced round the basin as far as Torphichen to the north of Bathgate. At Bowhousebog, a little south-west of Shotts, the coal is very thick (but unworkable on account of its many partings of clay), and is known from that locality as the Bowhousebog coal. Generally it is thin or even absent, but the fireclays associated with it are very persistent. Seams of clay of 8 to 10 feet frequently occur in bores through the horizon, and others are recorded not far below. This horizon lies from 72 to 96 feet

below the base of the Coal Measures and can generally be easily recognised in bores passing through the Millstone Grit. As at Hareshaw, scattered nodules of clayband ironstone may occur.

South Lanarkshire.

Millstone Grit rocks cover a considerable area in the district of Poneil, Douglas and Glespin, and include fireclays of workable thickness; these have been passed through in bores and exposures of fireclay horizons are seen at several points along the Poneil Water and in the Kennox Water at Glespin. Nothing, however, appears to be known of the quality of these clays from a refractory standpoint. The thickness of the Millstone Grit in the Poneil district is at least 400 feet.

Ayrshire.

The Millstone Grit fireclays of north-west Ayrshire have recently been investigated by Mr. G. V. Wilson and the late Dr. C. T. Clough: they seem likely to yield valuable refractory material.

The principal fireclay seams are found at the top and bottom of the Millstone Grit. Here they are separated by about 20 fathoms of volcanic rocks with interbedded sediments, which in this part of Scotland make up the greater part of the Series.

The lower fireclay appears to be widely distributed in North Ayrshire, but is sometimes absent or very thin. The seam is exposed on the Caaf Water, ¼ mile below Drumastle Mill, west of Dalry, and a 7 feet seam of clay on the same horizon has been observed on the north side of the Fenwick Water, south of Meiklewood, near Kilmarnock.

The same clay has also been met with in bores in the neighbourhood of Kilwinning.

Only the lower fireclay is at present wrought to any extent in Ayrshire: it is mined at Monkcastle, one mile S.S.W. of Dalry Station, by the Douglas Firebrick Co., Kilwinning. The seam here forms four beds of somewhat different character with a total thickness of 10 feet.

The upper fireclay of the Millstone Grit in North Ayrshire is a clay of somewhat peculiar character. It is described by Mr. Wilson as usually very hard, well-jointed, and with a distinctly conchoidal fracture.

The chemical composition of this clay is distinguished by the presence, in many cases, of from 4 to 10 per cent. of alumina in soluble form; the total amount of alumina present being sometimes as high as 47·57 per cent. Oxide of titanium, usually in the form of rutile, is also abundant.

The analyses and physical tests of this clay show that a clay with 9·04 per cent. of titanium may have a refractory index higher than Seger cone 35.

A similar hard bauxitic clay occurs in the Sanquhar Coalfield, and has also recently been met with by Mr. Wilson in the Island of Arran.

The outcrop of the upper fireclay has been traced eastwards from South Bay, Saltcoats, to Kilwinning, and small outliers of the seam have been observed at Lochwood and Smithstone, north of that town.

The clay is also exposed on the banks of the Lugton Water, east of Sevenacres Mains, and also 300 yards south of Caven Hill. From this point the crop turns to the south and is seen on the bank of the Annick Water E.S.E. of Fairliecrevock, and also on the Fenwick Water, S. by E. of Southcraig near Kilmarnock.

Physical and Seger cone tests of this clay from several localities have been carried out by Dr. J. W. Mellor for the Douglas Firebrick Co., Kilwinning. The results tend to show that the clay deteriorates in refractory qualities from west to east.

There appears to be an extensive field of good-quality clay along the outcrop for about two miles eastwards from Saltcoats towards Kilwinning. It is now being worked at the crop near Stevenston.

About four miles to the south of Kilmarnock rocks of Millstone Grit age outcrop near Spittalhill and extend in an easterly direction for a distance of 8 miles to the Killoch burn at High Holehouse. Here again contemporaneous volcanic rocks form a large part of the series, but the sequence is not yet known in detail. There is, however, no reason to doubt that the very refractory bauxitic clay, already described as overlying the Millstone Grit lavas of N.W. Ayrshire, occurs in this district also. It should also be observed that this belt will probably be found to extend a considerable way west of Spittalhill. Its actual extent and its economic possibilities are, however, not yet proved, and will require careful investigation in the future.

In South Ayrshire the Millstone Grit covers a considerable area to the south of Cumnock and appears also in the Dalmellington field. Volcanic rocks have not been met with so far at either locality; nevertheless, until the Millstone Grit sequence is more completely known, the possibility of their occurrence cannot be dismissed. At Dalmellington a fireclay lying some 20 fathoms above the base of the Millstone Grit (and about 50 fathoms below the well-known Blackband Ironstone) is worked by the Dalmellington Iron Company for the

manufacture of furnace bricks and blocks. It is interesting to find this fireclay corresponding roughly in its position in the Millstone Grit sequence with the Lower Fireclay of the central basin.

Fife and Clackmannan.

Strata of Millstone Grit age form a border to the Dysart and Leven Coalfield, and good sections are exposed on the coast near Pathhead and in the Den of Kennoway. They fringe the little coalfield of Kinglassie and further west cover a wide tract of country on the east side of the Clackmannan Coalfield. The sediments include fireclays, but of the refractory quality of these nothing is known. The thickness of the Millstone Grit in Fifeshire is variable; on the coast near Pathhead it has been estimated as about 700 feet. In the Markinch district it is some 740 feet, and probably equally thick in Clackmannan. In Eastern Fife, on the other hand, it is considerably less.

Midlothian.

In the Midlothian basin the Millstone Grit is rich in fireclays, but here again little is known of their quality. In the Portobello and Niddrie area the whole thickness amounts to 740 feet. Detailed accounts of the fine natural sections in the Bilston Burn and South Esk will be found in the Memoir of the Geological Survey on the Edinburgh district.[1]

Coal Measure Fireclays.

Coal-seats or underclays are wrought at a number of localities in Scotland with the coals associated with them, but with few exceptions they do not yield high-class refractory material. Some of them are worked regularly, others intermittently, and even to mention those that have at one time or another been tried for various purposes would require more space than we have at our disposal. It is hoped, however, that the more important of those at present worked are mentioned below.

Lanarkshire.

At Herdshill and Chapel Collieries, near Newmains, the floor of the Mid-Drumgray Coal is extensively worked. This fireclay at Chapel is grey, rooty and fairly hard, and furnishes excellent material for making refractory linings and goods of all kinds; its contraction is low and it is specially adapted for difficult shapes. The same seam at Herdshill, however,

1 *Mem. Geol. Survey*, 1910, p. 244.

is less refractory and is used mainly in the manufacture of sanitary ware.

The underseat of the Balmoral or Mill Coal is worked at Gartcraig in the Shettleston district and used partly in the manufacture of firebricks.

Linlithgowshire.

Several fireclays in the lower part of the Coal Measures are worked in the Armadale district; the most valuable is the underseat of the Colinburn Coal, which is used in the manufacture of refractory goods.

Stirlingshire.

Fireclays at several horizons are wrought in this county. At Roughcastle, one mile east of Bonnybridge, two fireclays of Coal Measure age are worked in addition to the Upper Fireclay of the Millstone Grit. One of these is about 5 feet thick and overlies the Slatyband Ironstone at the base of the Coal Measures; the other occurs five fathoms higher and forms the floor of a thin coal known as the Craw Coal of Bonnyhill; it is a sandy clay passing locally into a ganister closely resembling the ganisters of the Bonnybridge horizon.

At Callendar a 6 feet fireclay is wrought in the position of the Armadale Ball Coal, and is manufactured into firebricks and blocks, stove-backs, etc. At Carronhall Colliery a small amount of clay is raised along with the Craw and Coxroad Coals.

Ayrshire.

In the Kilmarnock district the underclays of several coal seams are worked on an extensive scale, mainly for the manufacture of sanitary ware, enamelled bricks and tiles, and ordinary building bricks, though second-class firebricks are also made to some extent.

Carboniferous Limestone Series.

Several clays underlying coal seams in the central division of the Carboniferous Limestone Series are also worked, and of these a few are used in the manufacture of firebricks and other refractory ware. At Prestongrange, in East Lothian, the floor of the Clay seam is intermittently wrought, and the fireclay below the Great Seam at Whitehill in Midlothian has also been used for firebricks. In Fifeshire the floor of the Four-foot Coal at Kingseat is worked; and a fireclay lying 6 to 7 fathoms under the Index Limestone is wrought at Lochead and Lilliehill. At Cardenden a clay above the Glass

Coal was used for firebricks, and several other clays have been, or are being, worked for various purposes. For manufactures which require a plastic clay the Kingseat material has been found particularly useful.

Calciferous Sandstone Series.

A fireclay in the Calciferous Sandstone, lying about 55 fathoms below the Hurlet Limestone, has been worked for some time at the Ferguslie Works, Paisley, both for refractory and ordinary bricks and tiles. The main seam consists of two beds, each 3 to 4 feet in thickness, separated by a 6-inch coal; another seam, 2 fathoms below, has also been wrought.

At the neighbouring Newton Pit a fireclay 2 fathoms below the Newton Coal was at one time raised, and a mine driven through a fault immediately north of the pit met with three seams of fireclay, 1 to 4 feet in thickness, separated by stone partings.

GANISTERS.

The ganisters or siliceous sandstones at present used in the manufacture of refractory goods are also chiefly derived from the Millstone Grit, where they are found in association with the fireclays both of the Upper and Lower zones, those of the Upper zone being most in demand.

Lower Fireclay Horizon.

A siliceous sandstone lying immediately above the main seam of the Lower Fireclay is used to a limited extent in the manufacture of "ganister" bricks at Glenboig. At Gain, where it separates the "white" or main seam from the "blue clay," it varies from a mere rib to a bed 12 feet in thickness. At Heathfield, Garnkirk, a siliceous sandstone, 22 fathoms above the fireclay, is used, with an admixture of fireclay, in the production of a "silica" brick. At Castlecary a white ganister lower in the sequence, and only separated from the base of the Series by a few inches of blaes, is also used, mixed with a sufficient quantity of clay to reduce the percentage of silica to approximately 85—87 per cent. for refractory products.

Upper Fireclay Horizon.

Bonnybridge is the only locality where ganisters are worked in association with the Upper Fireclay. There are sometimes one seam, sometimes two seams, of ganister. They would be more correctly described as ganister-like sandstones; and are generally light-colored, fine-grained, rooty and somewhat micaceous. The texture is fairly uniform and the grain varies

from ·075 to ·1 mm. Angular quartz forms the bulk of the rock with a fair quantity of white mica; the matrix is partly siliceous, partly argillaceous. The Bonnybridge ganisters as compared with English ganisters, which they approach very closely in some respects, have a less purely siliceous cement and a slightly higher percentage of alkalies and lime.

In addition to those of Millstone Grit age, a ganister lying immediately below the Gair or Calmy Limestone of the Upper Group of the Carboniferous Limestone Series is now worked to some considerable extent at Auchenheath, West Lanarkshire. The rock occurs in two beds, separated by a thin fireclay which is mixed and ground together with the two siliceous rocks. The lower bed has a very high percentage of silica.

Among the potential sources of material for refractory products particular mention should be made of a bed of ganister found in association with the lowest limestones of the Carboniferous Limestone Series along the southern and eastern margins of the Midlothian Carboniferous basin. A highly siliceous rock has been met with on this horizon at Carlops and Macbiehill in Peeblesshire, at Middleton and Vogrie near Gorebridge, and at Chapel Point, a few miles east of Dunbar; and it seems likely that this bed may be continuous at this horizon around the greater part of the basin. This ganister is now being opened up between Carlops and Macbiehill, where it is between 2 and 3 feet in thickness and has a very high silica percentage. The results of recent analyses and firing tests indicate that it is a rock of good refractory quality.

A ganister much in the same stratigraphical position, found near Blackwood, in Lanarkshire, on the west side of the Clyde Valley, has lately attracted some attention.

Several other sandstones of Carboniferous age in different localities in Lanarkshire, Midlothian, Dumfriesshire, Ayrshire, and Arran, have also been suggested as possible sources of refractory material, and a good many of these have been analysed.[1]

Full analyses and the results of physical tests of the fireclays and ganisters referred to in this paper will be found in the "Report on British Refractories" (now in the press), forming Vol. VI in the series of "Special Reports on the Mineral Resources of Great Britain," prepared by the Geological Survey. This report also contains a detailed account of the principal fireclay works, the nature of the material, and the uses to which it is applied.

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[1] See Report referred to below.

DISCUSSION.

Mr. J. G. ROBERTS:—I have been particularly interested in this paper, and I am sure all clay workers are indebted to the Geological Survey for the valuable information which has been brought together.

We have, of course, heard a good deal about the Glenboig seams, which are, commercially, the most important fireclays in Scotland. My own experience has been with other clays, mainly those lying in the Coal Measures and Carboniferous Limestone Series. These clays, while seldom possessing the highest refractory qualities, are very good clays for many purposes. They are fairly pure and often very constant in composition. Their softening points usually run from K. 30 to K. 32. Some of them contain siderite nodules. Some are liable to vary in composition, as delivered from the pit. Kingseat clay, referred to in the paper, rests on a highly siliceous clay, and there is also a micaceous layer just above it. Needless to say, great care is necessary in mining this clay or serious variations in quality and character may occur. The Ferguslie clays are very clean burning plastic clays, and I am hoping they may be some day exploited farther to the south.

Mr. T. ARTHUR ACTON:—I was much interested in the able description of the ganisters of South Scotland, and in the remarks made in the discussion on the paper by Professor Fearnsides.

At the last meeting I suggested that it was desirable for silica brick makers to distinguish between the raw materials used for making bricks. Ganister, originally a North of England mining term, applied solely to the highly siliceous rocks found as "seat-earths" in the Lower Coal Measures should be confined to these rocks, and the term quartzites, or Dinas-type rocks (the German Dinas Stein) should apply to the true quartzites, from whatever geological horizon they were obtained. No doubt ganister could be described as a quartzite, but the Yorkshire ganister petrologically examined showed a somewhat peculiar and special structure. I am not satisfied that these peculiarities exist only in the Yorkshire Coalfield, and I would like to ask Professor Fearnsides whether, in his opinion, any special conditions were likely to have been in operation at the time these ganisters were deposited, or any subsequent conditions which led to the regular distribution of the impurities around the quartz grains which is such a marked feature of these particular rocks. Professor Fearnsides used

the term "chemical" conditions. I think he would, on reconsideration, prefer the word "climatic."

The question as to the merits of ganister and quartzite for making silica bricks had been mentioned, but no reference made to the fact that the highest grade American bricks are made from pure quartzites—those which I have examined present the same chemical and petrological characteristics as the quartzites used in this country.

Mr. G. W. MOTTRAM:—After this paper on these "ganisters," which are not ganister, one would like to have a definition of ganister. What is ganister, and what distinguishes it from other silica rocks? What is the theory of its formation? As I understand it, the term is peculiar to the Sheffield district, denoting the silica rock, forming the seat of the Halifax Hard Bed Coal in the Lower Middle Coal Measures.

Until the term ganister became an established trade name, denoting special qualities when used for the manufacture of silica bricks and for furnace linings, it was not used or even known except in the Sheffield district. A mixture of sand and fireclay was in use for foundry purposes long before ganister was discovered to be of value for this purpose, and while this mixture is still in use in some districts, it has now fallen into line with the silica rocks and adopted the name ganister.

Professor FEARNSIDES:—Preceding speakers have raised the question as to how the rock-species "ganister" may be reasonably precisely defined, and by one speaker it was mentioned that the name seems to have originated in the Sheffield district. In his hand-book to "The Early History of Stocksbridge and District," a trusted antiquary, Mr. Joseph Kenworthy, states that ganister was formerly used in the Don Valley district "for road-making exclusively," but in an undated report written by John Farey, who lived 1766 to 1825, we find it referred to as "a peculiar kind of hard stone, called crow-stone or ganister, which, though an admirable material for road-making, yet when pounded fine and kneaded with water, has all the properties of fireclay." "Joseph Bramall, senior, of Oughtibridge, was the first to use ganister for furnace linings. The earliest experiments are said to have been made with road-scrapings—which is not improbable, because, as we have seen, ganister-stone was used for road-mending exclusively, a century ago and more."

The date at which these experiments were carried out is somewhat uncertain, but it is said that already in 1838,

Huntsman, the pioneer of crucible steel-making, had already begun the use of road-scrapings, which he bought instead of fireclay, for the repairing of the walls of his crucible holes.

The suitability of ganister as a refractory lining for vessels required to contain steel at high temperatures seems to have been first taken advantage of when Sir Henry Bessemer introduced the process which bears his name, and one of the earliest printed references recording its application is to be found in Sir Henry Bessemer's paper on "The Manufacturing of the Malleable Iron and Steel without Fuel," read before the British Association at Cheltenham in 1856.

From the time when, in the early sixties, first Messrs. John Brown & Company, of Sheffield, and hardly later, Messrs. S. Fox & Co., Ltd., of Stocksbridge, adopted the Bessemer process, the use of ganister as the most manageable highly-refractory "acid" material, has advanced continuously, and the annual consumption of Don Valley ganister has increased from something less than 1,000 tons forty years ago, to more than fifty times as much in recent years. As the demand has grown, so it has been recognised, at any rate in Sheffield, that the best of the ganister comes only from one, or at the most two beds, which beds occur in immediate association with coal seams of peculiar type. I refer particularly to the Halifax Hard Bed Coal, which, almost alone among the Yorkshire coal seams, has a roof-shale bearing abundant marine shells. There are many details which one might refer to when describing the micro-structure of ganister, but the most remarkable geological feature about the ganister of Sheffield is that it occurs as the latest member of series of sediments apparently deposited under estuarine conditions, and the coal seam which rests directly upon it is immediately overlain in turn by sediments which in origin are marine. Myself I am of opinion that the physico-chemical peculiarities of Tyne ganister rock, which are sufficiently pronounced to determine that silica bricks made from it can be soundly burnt off with an expenditure of fuel per ton of product no more than half what is required to manufacture quartzite bricks, are to be attributed to the physico-chemical conditions which accompany the rather sudden change at the time of its deposition from estuarine to marine conditions; and I would like to see some reference made to the geological conditions of its origin when the rock-species "ganister" is defined.

In making this suggestion I may say that I do not hold any brief for Sheffield manufacturers, nor do I believe that there are not ganisters in districts remote from Sheffield. On the contrary, I think there is good reason to accept as true

ganisters rocks which occur at several horizons among the Millstone Grits of Northern England, and probably also among the Lower Carboniferous and Millstone Grit Series of Scotland. It may well be too that the refractory silica rocks which occur among the Middle Jurassic of East Yorkshire are true ganisters in the geological sense, and microscopic evidence suggests that some of the "Suss-Wasser-Quartzites" among the Miocene rocks of the countries on the east side of the North Sea are also worthy of the name ganister.

It has been with very great interest that I have listened to the conspectus of Scottish resources of refractory materials, as presented by our friends of the Geological Survey. I am sure that we are all glad to know that the reserves of refractory clays in Scotland are so illimitable, and it is interesting to note that in Scotland, as in almost every coalfield from South Wales to the Grampian Hills, the main reserves of the refractory materials are associated with rocks at or near the horizon of the Millstone Grit. As a geologist, it occurs to me that this coincidence of geological horizon must be attributed to the climatic conditions which prevailed in Britain in the Mid-Carbonaceous Period. I do not know what those conditions were, but it is clear that almost everywhere within this area, rocks which were exposed to denudation and after transport were deposited to form those special beds which now form our refractory clays, ganisters and refractory quartzites, were so subjected to the action of solvents that they lost whatever alkalies and alkaline-earth materials they may have contained more completely than at any other geological period before or since.

In conclusion, I should like to ask a question. It has been brought to my notice that the best firebricks made from either the Lower or the Upper Fireclay groups of the Millstone Grit Series, both in the Glenboig and Bonnybridge districts, when heated to a comparatively high temperature throughout their mass and subjected to the action of flame, cover themselves with a film or layer of glazed material, which, unlike the equivalent melt produced under similar working conditions upon the face of many high quality English firebricks, does not "wet" and run into the rest of the brick, but on the contrary ends against it at a well and sharply defined line. Many users of refractories will be exceedingly grateful for any information which throws light upon the cause of this well-recognised characteristic of the renowned best qualities of Scottish clays.

Mr. P. MacNair: said that he considered it exceedingly appropriate that the opening paper dealt with the geological and geographical distribution of the fireclays and ganisters of Scotland, and the Ceramic Society was to be congratulated on having this subject laid before them by such well-known authorities on carboniferous stratigraphy as Messrs. Hinxman and MacGregor. A very clear description had been given of the important deposits of fireclay in the Millstone Grit Series to the east of Glasgow, and he was particularly interested in the somewhat short account that had been given of the Upper and Lower Fireclays lying respectively at the top and bottom of the volcanic zone which occupied the Millstone Grit position in Ayrshire. He would like to ask the authors of the paper if they regarded these two Ayrshire fireclays as the equivalents in time of those found to the east of Glasgow.

Mr. MacNair thought that few, if any, of the deposits that had been described—strictly speaking—came under the definition of a ganister. Reference had been made to a highly siliceous rock that had recently been met with in the Lower Limestone Series of the Midlothian basin which was considered by the authors to mark a definite origin in the series. He (Mr. MacNair) had recently paid some attention to the stratigraphy of the Midlothian basin, and he was quite satisfied that this ganister occupied a position between the North or Middle Skateraw Limestone and the next limestone in the series which was known at Skateraw as the Chapel Limestone. This he had been enabled to make out by the examination of a large number of sections on the east and west side of the basin. In his opinion the ganisters from this district, and from certain other localities in the same series, approached more closely to the Sheffield type than any others that we had in this country.

Mr. Wm. Donald:—The authors have referred to bauxite deposits in Ayrshire, and I have prepared some notes about the bauxites I have dealt with in the past so that the investigators may realise their properties and importance.

The silicates of alumina are very variable in composition and give a great variety of refractory products.

It is interesting to compare the average chemical composition of these bricks ranging from those high in silica to those high in alumina.

Oxygen Ratio	Bricks	Average Chemical Composition Excluding Impurities	
		Al_2O_3	SiO_2
1-32	Silica Bricks	3·8	96·2
1-10	Ganister Bricks	10 1	89·9
1-2	Fireclay Bricks	35·6	64·4
3-4	,, ,, ...	46·1	53·9
1-1	Bauxite Bricks	53·0	47·0
3-1	,, ,, (French) ...	77·1	22·9
10-1	,, ,, ,, ...	91·8	8·2
15-1	Alundum Bricks	94·4	5·6

There is one bauxite that I know with about 65 per cent. Al_2O_3 and 25 per cent. Fe_2O_3 which is very infusible, and also another bauxite high in titanic oxide, evidently replacing silica. Each of these bauxites is very infusible. The possible relations between silica, alumina, titanic oxide and iron in refractory bauxites are exceedingly interesting. Alkalies are the most dangerous impurities.

In 1872 there were great demands for aluminous earths for alum manufacturers. One of these, which is found at Beaux near Marseilles, and which is called bauxite, and another found in Germany which is called Wochenite, began to be used then. While geologists hold that they are easily recognisable from each other (Ref. I), and are both recognisable from the bauxites and high-aluminous earths found in this country, the bricks that we have manufactured from them are all as easily recognised to be members of the same high alumina group as different fireclay bricks, or different silica bricks, are able to be recognised as members of their respective groups.

At that time in Scotland there was at least one firm, and in Manchester there were several large firms engaged in alum manufacture, and when the Eglington Chemical Co. acquired limestone quarries in Co. Antrim in 1873 they had a search made for the Irish bauxites that were known about 40 years before (Ref. II) to exist in the neighbourhood, and they discovered the deposits of Cullinane near Glenarm, and later those at Ballintoy. The quality of the bauxite in each mine was very irregular, bordering occasionally on the purity of the French bauxite, but the bulk of the material had much less alumina, while some of it was little better than the neighbouring plinthites. (Ref. III.)

We began to make bauxite bricks in 1885, and I have not traced that they were made elsewhere earlier than that, but the trade in this country has not been developed owing to the bauxites or alunites so far found in sufficient quantity

having contained excess of impurities. Bricks made from these and fired at heats used for burning silica bricks with the same atmosphere in the kilns are easily fused and melt into each other. A much greater percentage of grog is required when making bauxite bricks, which makes them more costly to manufacture than fireclay bricks are, and if they are to command the higher price they must be made from good deposits. These are available both in France and America, where there are considerable demands for bauxite bricks for special purposes, one of these being the lining of rotary cement kilns.

A statement that may interest Scottish fireclay brickmakers and others who mine Scottish fireclays is given by John Percy in his *Metallurgy* (Ref. IV), that shows how in the carboniferous series the average chemical composition of the ash of the coal is closely related to the average chemical composition of the clays above and below, with the exception that the alkaline impurities are most largely held in the upper clays and particularly in the coal which has saved the contamination of these alkaline impurities with the clays below.

With reference to Scottish ganisters and quartzites, a rough and ready guide in the manufacture of silica bricks is to record their weight per 100 cubic inches when the bricks are being discharged from kilns before they have absorbed moisture, or after any moisture they have absorbed has been driven off.

Given purity of average chemical composition the ganister or quartzite bricks that will give the best results in the furnace are the bricks that have the greatest weight per 100 cubic inches. In manufacturing silica bricks you have to allow for sufficient porosity to enable expansion to take place without disruption. Given whole bricks after the necessary firing, the best are those that have most substance.

A good way to measure this is to immerse a whole brick, after oiling the surfaces, in a suitable glass vessel filled sufficiently with water, the vessel to have a recording scale either on itself or on a neighbouring vessel of less diameter that measures the water level and the rise of that level per cubic inch when the brick is immersed.

The bricks should be weighed before oiling, and with the knowledge of the cubic contents the weight per 100 cubic inches can be calculated, and that figure should be multiplied by 1,000 so as to record the weight per 1,000 bricks, which has more significance to brickmakers. If there is a variation of size per 10 cubic inches, or in weight per 1,000 bricks of that size, there is some stage of the manufacture that requires attention.

Average samples of silica bricks from three districts were tested some years ago, and calculating the weights of 100 cubic inches and multiplying these weights by 1,000 the following were the results:—

1.	First quality silica bricks from Sheffield district	55 cwts. per 1,000
2.	Second quality silica bricks from Durham district	52 cwts. per 1,000
3.	Second quality silica bricks from Scotland	49 cwts. per 1,000

There was little variation in the average chemical compositions and they were classed as to quality in their reputed ability to withstand the highest heats of acid open-hearth furnaces in the most trying conditions. This shows clearly that weight is to be desired, and that the Sheffield and Scottish raw materials then used were very different in certain physical characteristics.

Reference I.—Manchester Geological Society. Volume 22, page 461. 1892/94.

Reference II.—Thomas Thomson, *Outlines of Mineralogy*. Volume 1, page 323. (1836.)

Reference III.—*Tertiary and Igneous Rocks of Skye*. Published by Geological Survey, page 47.

Reference IV.—John Percy, *Metallurgy*. Section on *Fuels*, page 278.

Mr. Wm. Douglas:—I can only add a very few details to the valuable paper contributed by Messrs. Hinxman and MacGregor, and congratulate them on the prospect of their paper becoming a text book on the geology of the refractory clays of Scotland. I am pleased to note that the authors of the paper correlate the fireclays found near Dalry with the Lower Fireclay horizon of the Millstone Grit. In this connection the section seen on the Caaf Water is very interesting. We can there see nearly the whole thickness of the Millstone Grit in this part of Ayrshire. In the bed of the burn at Drumcastle Mill we stand on the limestone. Following the burn through a gorge we find a ten feet seam of fireclay on both sides of the water. Above it a bed of sandstone probably forty to fifty feet thick (if we could see it all). Further down the burn we find overlying the sandstone a section of fireclay about twenty feet thick with a thin coal on top of it, a few more feet of strata brings us to the "twenty fathoms of volcanic

rocks." Where these have been quarried for road metal they rise to the surface of the ground. At this part we do not see the bauxite clay at the top, but it appears about a mile further to the south. The section at Monkcastle is practically the same. The bottom part of the 20 feet seam is still 6 feet thick and has the reddish tint often seen in the lower fireclays east of Glasgow. It is separated from the upper seams by a hard band of siliceous rock about 10 inches thick. Meantime only the upper seams are being wrought.

III.—Refractories and Modern Kilns.

By J. G. Maxwell.

BEFORE discussing the various types of kilns suitable for burning firebricks and fireclay blocks it would be as well to look into the various types of fuel available in this country for the purpose of firing such kilns. These are:—

(1) Town gas.
(2) Oil.
(3) Producer gas.
(4) Coal.
(5) Peat and lignite (gasified).

We may at once dismiss town gas and oil as impracticable propositions in this country, unless the latter be ultimately discovered in quantities permitting of industrial use, as their cost is prohibitive compared with coal or producer gas. Consequently the two fuels that we have available for firing high temperature kilns in this country are producer gas and coal. Peat and lignite require to be gasified to be used with proper effect, for owing to the 40 per cent. to 50 per cent. water in an air-dried sample of the former it is not suited for use direct in a firehole.

The advantages of firing with producer gas as against coal are:—

(1) Temperature under complete control.

(2) High temperatures obtained more economically and speedily than with coal, and any given temperature reached is more easily held in the kiln than with coal, and with comparatively no fluctuation.

(3) Great cleanliness of burning if provided with adequate supply of air.

(4) Great saving on wear and tear of kiln.

There is, or was, a considerable prejudice in this country (for many years) against the use of producer gas for firing brick kilns on account of explosions and unsatisfactory burning due to causes not sufficiently understood. The proper distribution of gas in the kiln was not carried out with necessary relation to the air supply needed for combustion, and the early

efforts resulted in parts of the kiln under full fire being apparently much overburnt, and other parts underburnt. Repeated failures, however, have their value, and have put kiln builders on the right path, and at the present day proper distribution of the gas is thoroughly understood and arranged, and an equal heat obtained in all parts of the kiln.

Having pointed out what in our opinion constitute the main advantages of gas firing over coal-firing, we shall assume that the types of kilns which we describe are gas-fired, though it is quite possible to fire each type with coal.

The three best-known types of kilns for refractory goods are:—

(1) The continuous annular shape gas-fired kiln.

(2) The continuous annular shape chamber type gas-fired kiln.

(3) The continuous tunnel and car kiln.

We should like here to point out that we do not consider all these three types are suitable for any and every kind of ware, as each type produces different conditions in actual working.

The continuous annular shape gas-fired kiln, as is well known, consists of an endless tunnel divided into a number of chambers, from 16 upwards, according to the class and output of material required. There is really no division between these chambers, the only thing which divides off one chamber from another are the entrances to the kiln by the wicket ways, and also in some cases by a drop arch within, which is used in cases where the material shrinks largely in the burning, and would leave a gap between the crown of the arch and the top of the bricks, allowing the escape of a fair amount of heat over the tops of the goods.

The ordinary gas-fired continuous kiln is, in principle, exactly the same as the ordinary coal-fired continuous kiln. The gas is generated in the gas producer, and the main gas flue surrounds the whole kiln. From the main gas flue branch flues of smaller size connect with the chamber and are controlled and regulated by valve dampers. These branch gas flues are provided with suitable size openings and carried through the arch and floor of chamber, and on the top of these openings removable perforated fireclay pipes are stacked vertically. These pipes are commonly called gas candles and when ignited the gas spreads outwards in long narrow flames across the path of the travel of heat. Sometimes these candles are built in a temporary manner with the bricks.

The main flue for receiving the products of combustion is situated in the centre of the kiln, and is connected with each

chamber by means of two damper valves. One of these is situated on the inner wall and the other on the outer wall. This system of two valves to each chamber gives a much more perfect control and even draught in all parts of the chamber than if only one damper per chamber were provided.

This type of kiln presents certain disadvantages which cannot in everyday working be entirely overcome. In the first place the air required for the combustion of the gas passes through the open wicket and then passes through chambers containing bricks which are cooling off, and in doing so becomes pre-heated, and thus the air is brought to the gas candles in a highly heated condition by regeneration. The amount of air, however, that enters these wicketways is under no control at all, and is, of course, often a great deal more than is necessary for the complete combustion of the gas. It is generally reckoned, speaking roughly, that five times as much air is supplied to the gas candles as is theoretically necessary for complete combustion. Assuming for a moment there were seven rows of gas candles across the chamber firing at the same time, the first row would receive a good deal more air than was necessary for complete combustion, the row behind a supply of air in diminished quantity, till probably the last two or three rows would receive insufficient air for complete combustion, for it is obvious that there is no practical means of regulating this air supply. If just sufficient air was admitted through the open wicketways of the kiln to supply enough air for complete combustion to the first row, the gas burners of the second and following rows would obviously not receive sufficient.

Further, the air required for combustion, entering by the wicketways, in passing through the chambers of cooling bricks becomes highly heated, and consequently specifically lighter than the heavy gas. This gas, as stated above, enters from the floor of the furnace, and consequently there cannot be the ideal mixture of gas and air so essential for perfect combustion.

Owing to the excessive air supply the conditions in the kiln are strongly oxidizing, though it is possible to obtain some reducing conditions by setting the goods very much closer, thus cutting off the air supply to a considerable extent. This, however, is only a makeshift, for the tighter setting of the goods produces slower travel of the kiln and so reduces the output.

If it is desired to hold the heat in any one section of the kiln for a longer time than usual, *i.e.*, to give soakage to the goods possibly because of their large size and greater thickness it is practically difficult to do this without a rather heavy expenditure in gas to keep up the heat or prevent the stealing forward of cold air from the back.

In spite of these imperfections this type of kiln is a really good one, and is undoubtedly the *cheapest* and most simple type of gas-fired continuous kiln to erect, easy to set, and draw and operate.

We now come to the chamber type kiln. This is capable of reaching very high temperatures, and giving prolonged soakage to refractory goods, and has been employed with the greatest success for burning carbon electrodes in this country and abroad, and also for burning magnesite and silica bricks and very high grade firebricks.

The gas-fired continuous chamber type kiln consists of a number of connected chambers. Differing from the ordinary gas-fired continuous kiln already described, and which has no divisional walls, this kiln may consist of a long tunnel having division walls or a series of transverse arches connected one with another. The main gas flue surrounds the kiln as in the previous type, and likewise has its smaller branch flues to each chamber.

The gas from the main flue is connected by these branch flues to each of the four corners of the chamber where it rises up in a pocket or bag, sometimes called a flash wall.

After ignition in the chamber the burning gases descend through perforations in the floor to exit flues that connect to the main flue or to the chamber ahead.

The supply of gas to each of the four corner pockets or bags is controlled by separate gas valves. The air for the combustion of the gas having been highly heated by regeneration in passing through chambers containing burnt goods cooling off is brought by flues to a point just above where the gas enters the pockets or bags. Each air supply flue is regulated by a damper, so that the exact amount of air required for the combustion of the gas is under complete control.

As compared with the previously described open tunnel type of gas-fired kiln this chamber type form offers a considerable number of advantages, although it is generally assumed that the chamber type is not so economical in fuel consumption as the ordinary continuous kiln. This is undoubtedly true, as the extra walls absorb a great deal of heat, but the regulation of the air supply and the gas being under such complete control in the chamber type kiln the economy effected in producing a perfect admixture of gas more than counterbalances this.

As previously pointed out, in the ordinary continuous type kiln the air supply is under no control whatever, and further the air, when it does arrive in the ordinary continuous type kiln to the candles is supplied in a distinctly rudimentary manner, whereas in the chamber type kiln the gas and air enter

at practically the same point, both supplies being under complete control, the gas and air become intimately intermixed in the gas bag or pocket.

Further, there are a number of other advantages which follow from this complete control of the gas and air supply, and the perfect admixture of the air and gas before becoming ignited, which do not exist in the ordinary continuous kiln. The chamber type kiln is capable of reaching considerably higher temperatures than the ordinary gas-fired kiln, one reason for this being that the enclosed chamber retains its heat much longer than the ordinary open type, and consequently the air for the combustion of the gas is supplied very much hotter to the gas, and also at a more constant heat.

The following disadvantages apply to both of the kilns described.

Owing to the length of the kilns the gas from the fixed producer has to travel a considerable distance to reach the far chambers of the kiln, and it is not practical to have the main gas flue from the producer built in the kiln itself where it might be kept warm. Owing to the danger of possible leakages through the expansion and contraction of the kiln the main gas flue in the best type of gas-fired continuous kiln is constructed *outside the kiln*, and, as previously stated, to reach some parts of the kiln it has to travel considerable distances, and in such a flue it is quite possible that the gas may lose as much as 50° to 75° C. per metre run. Far greater heat losses, however, occur from the constant heating up and cooling off of the walls of the kiln. The amount of heat absorbed by the brickwork is very great, and when the burning is carried forward that part of the kiln which has been fired off and is cooling down only yields up a small proportion of its radiant heat to be drawn forward.

We finally come to the type of kiln we believe will be *the kiln of the future* for most kinds of high-class refractory ware, and this is the gas-fired continuous tunnel and car kiln. The general principle of these kilns is so well known that it is hardly necessary to enter into an elaborate description of the same. Roughly speaking, it consists of a long tunnel which is theoretically divided into three parts: (1) the preparatory or entrance zone, (2) the actual firing zone, and (3) the cooling off or departure zone.

The air for combustion enters the departure end of the kiln, and passing through the cars containing goods which are cooling off becomes highly preheated, and is used for combustion of the gas, and eventually the products of combustion are drawn from the firing zone through the preparatory zone, and depart

from the kiln at a point near its entrance. Consequently as the cars which are loaded with goods enter the kiln they travel in the opposite drection to the products of combustion leaving the kiln; therefore they come into contact first with the coolest gases and gradually get hotter and hotter until they approach the actual firing zone in the middle of the kiln. The length of the entrance or preparatory zone and the length of the departure or cooling zone are of course matters of the greatest importance, and on the knowledge of the kiln builder as to the requisite proportion of these zones the success of the kiln largely depends. Some materials have to be heated up very slowly before they enter the firing zone, and often have to be cooled off very gradually before departing from the kiln. These questions are matters of actual experience, varying in every type of manufacture and with every kind of clay, and no definite rule can be laid down that will apply in all cases.

The constancy of temperature obtained in these kilns is remarkable. but the principal cause of this is due to the stationary fire.

Further, owing to there being a fixed firing zone, the gas producer can be placed quite close to the firing zone of the kiln. From here to the farthest point in the firing zone it has very little distance to travel, consequently the gas loses but little of its heat in its course from the producer to its actual point of ignition. A fixed firing zone also obviates the heavy losses arising from the constant heating up and cooling down of the walls of the kiln in the other types of continuous kilns described.

Owing to all parts of the kiln being always kept at the same temperature the kiln structure itself is not, of course, subject to constant expansion and contraction, and thus costly repairs to the brickwork portion of the kiln are nil.

It is frequently advanced by people who have never seen a good modern tunnel and car kiln at work, that the wear and tear on the ironwork must be very great. This is an absolute myth. The ironwork of the cars is so well insulated that one can walk underneath such a kiln from one end to the other and place one's hands on the axles and wheels of the cars without any discomfort. This statement is based upon actual experience at a kiln in operation here in England, where the goods in the firing zone are burnt to 2,462° F. It is therefore clear that no damage can happen to the cars from excessive heat.

From the point of view of the comfort of the workman, as the cars are mechanically introduced and withdrawn from the kiln, this method of burning is ideal, the whole of the setting and unloading of the cars being done in the open, in

clear light, without dust or heat drawbacks. Further, the gas producer means only one central point for the delivery of fuel and the removal of ashes, whereas in coal-fired kilns the supply of coal and the removal of ashes has to be arranged for each chamber.

The tunnel and car kilns so far erected in this country are mainly used for burning majolica tiles, stoneware and pottery, but from actual tests made in kilns erected for stoneware burning the applicability and suitability of this kiln has been demonstrated to the highest satisfaction for burning firebricks, silica bricks, terra-cotta, glazed bricks, sanitary ware, lime, dolomite, and many other purposes.

The rigid conditions of entry and discharge of loaded cars prevents over and under burning, when the exact time and temperature has once been ascertained.

The fuel economy obtained places these gas-fired tunnel and car kilns as far ahead of other continuous kilns as they are ahead of the intermittent type.

The reason for this great fuel economy is obvious, as having once raised the heat of the firing zone to the required temperature, all that is needed is to maintain this temperature against the trifling radiation losses of the kiln structure and goods. As the area of firing is constant it is not subject to losses from cooling down. Goods nearing the point of discharge return their heat to the firing zone and, combined with the heat produced there, passes forward to the entrance end of the kiln and communicates that heat to the oncoming goods. There is thus everywhere the continuity of heat action, exactly as in the ordinary continuous kiln, but added to this is the fixed firing zone, the brickwork of which, once raised to the desired temperature is retained at that temperature, and not allowed to cool down only to reheat, as in the ordinary form of continuous kiln.

In the case of refractory goods requiring in coal-fired kilns a heavy expenditure of fuel, this valuable economy of heat is made much more manifest, indeed the higher the greater the economy derived.

Further, the output of this type of kiln is very large. As a rule with most products that require very high temperatures, they also require prolonged soakage and a good allowance of time for raising and lowering the heat. By increasing the length of the kiln and by increasing the number of gas burners such lengthened periods are obtained. By travelling also at a reduced speed through a shorter kiln a longer soakage can be obtained.

There is a latitude in the working of a tunnel and car kiln that is most surprising. Many people imagine that once started the kiln cannot be halted, and that continuous running day and night without intermission is absolutely essential.

This is not so. The kiln can be slackened down for week-ends for instance, or where there is a shortage of goods to be set, and yet without the slightest detriment to the quality of the ware produced, it merely resolves itself into a question of cutting off the supply of gas to the kiln, by either closing down some of the gas valves entirely, or the whole of them partially, and moving the cars in and out of the kiln at long intervals.

DISCUSSION.

Mr. W. J. JONES:—The best points of the tunnel kiln have been put forward in this paper. I am not certain that I should be disposed to agree with regard to the relative merits of the three kilns. It would be very interesting to me to know whether this particular type of kiln is used in burning dolomite, for instance. I am not at all sure that the temperatures to which these car kilns have been worked do approximate to anything necessary for calcining dolomite. I see that the author of the paper states that there is a kiln in operation in this country. Probably the maximum is in the neighbourhood of cone 12. We should have to get to something very much higher for dolomite, magnesite, or even silica bricks for that matter. Another thing occurs to my mind, and that is, as to whether or not in order to obtain the greatest economy the kiln of this type does not require to be worked day and night and Sundays without any respite or intermission—passing the material through continuously.

It seems to me that to work a kiln of this type you ought to subject the material that is being burnt in that kiln to an even working from the moment it enters the kiln until it emerges completely burnt. I should be very glad if Mr. Maxwell would answer in the TRANSACTIONS.

There is another point that occurs to my mind, and that is, you always have your maximum heat in one place, and when the kiln requires to be repaired you have to close down the whole business until so repaired, whereas in a chamber kiln it can be repaired as the chambers come off in regular rotation. That is another point that has to be considered in regard to the relative merits of kilns. I only offer these remarks to start the discussion.

Mr. WM. DONALD:—I would like to tell the meeting of an experience with tunnel and car kilns which I had, as I think if that is to be the kiln of the future for burning firebricks it will be so all the sooner if the known facts are collected and studied.

It was through Mr. Maxwell that I was permitted to inspect and have tested two tunnel and car kilns built by his firm. One was 250 feet long and the other 300 feet long.

Certainly if the heats required can be attained, and if uniform heat can be applied at top and bottom of the kilns in such a way that the bricks in the centre of the moving wagon loads are thoroughly burned, this tunnel and car kiln is THE kiln.

When I inspected the kilns the shorter one was under fire, and I saw the heats required for firing pottery. At first they had experienced difficulty owing to the atmosphere tending to be reducing, but with the better air supply there was an oxidizing atmoshpere, and the kiln was doing capital work. The longer kiln was having the air supply altered, and I was able to inspect the internal arrangements. The tunnel was 8 feet wide and about the same height. The cars were eight feet wide and about 4 feet long if I remember right. In both kilns, burning pottery ware, the practice was to have the cars issuing from the tunnel every 45—60 minutes. The shorter kiln had four burners on each side, the longer one seven burners, but only five were being used. That gave the goods about four hours in the small kiln and five hours in the large kiln at the highest temperature. Later I had the temperatures observed by a Féry pyrometer, and in the large kiln the heat at the top was 1,280° C. and at the bottom was 1,190° C. The weight of the goods on the cars was about 30 cwts.

It was proposed to burn a car load of our goods, but it was found that the car axles and the rails were too light for the heavy load that they would be. Ultimately it was decided that we should send 1,000 firebricks in the unburned state, and that these should be distributed in different parts of the various cars. At that time we had a contract with Mr. Douglas of Kilwinning, and it was 1,000 of his firebricks that were sent, so that we could compare the firing of his kiln with that of the tunnel and car kiln. It will no doubt interest him to see the result.

The bricks were sent in the green state and on arrival were in good condition. It was expected that the kiln should be able to take the bricks from the moulding machine, and no attempt was made to pre-heat them in drying stoves. It was mainly those on the outside of the settings that showed the

cracking most, but that indicates how irregular the heating was even at the initial stage. The cars travelled the 300 feet in 60 to 68 hours. Had any longer time been allowed it would have endangered the other goods being burned. The goods had 30 hours heating up, about five hours at the highest temperature, and about 30 hours cooling. As I said earlier, the temperature at the top of the kiln was 1,280° C. and at the bottom 1,190° C. As the bricks weighed most they had to be placed in the bottom with the pottery on top to baffle the flame, which was baffled as effectively as possible. When burned the bricks had a very white appearance, and remained unaltered when reburned in the same kiln several times. Different types of kilns produce different burning atmospheres, and each of these different atmospheres has a peculiar effect on the goods being burned, sometimes the difference being most marked.

With even temperatures, and if the temperature is held there is no doubt in my mind that the heat could be raised in the tunnel and car kiln, but there is the question whether it could be raised more economically than in continuous kilns where the heat travels. With 12 or 24 burners on each side, or with the smaller number of burners and the longer exposure to the highest temperatures, the desired result could be attained; but in the one case the length of the kiln would be much greater, or in the second the production much less. With the longer kiln the hydraulic ram would have to move the wagons with 450 tons of material every one or two hours from a stationary position. This would not only entail considerable strength in the hydraulic ram, but the hindmost cars would bear a great strain moving those in front against the advancing heat.

I know that Mr. Maxwell must have considered the matter very carefully before coming to his conclusions; but the matter is of so much importance that I think it only right that the pioneers in the use of the tunnel and car kilns for firebrick burning should have as many facts as possible before them when considering the advantages and difficulties. It is only in that way that brickmakers can set Mr. Maxwell to overcome the difficulties and give them sufficient guarantees about the result.

Mr. C. W. THOMAS:—1. I cannot agree that town gas for firing kilns is quite an impracticable proposition. Producer gas has about one-third the calorific value of ordinary town gas, and, while the cost of producer gas is from 6d. to 9d. per 1,000 cubic feet, town gas, at any rate before the war, could

be obtained in some districts at 1/6 to 1/8 per 1,000 cubic feet. So that it would appear that in calorific value, and in certain districts, there is not much in it.

Several of the advantages claimed by Mr. Maxwell for producer gas, as, for instance, the exact control of temperature, depend entirely on the manner in which the producer is worked, which is not always easy to maintain at a regular figure. In this respect, also, town gas would have an advantage.

2. I think Mr. Maxwell might have said something about the capabilities of the coal-fired continuous kiln, of the so-called Belgian type. For the bulk of ordinary refractory work this type of kiln takes some beating. Fuel consumption of about 10 per cent., with temperatures up to cone 12, can be obtained with great simplicity of working, and without difficulty. In fact I doubt if the tunnel and car type of kiln can show better figures for fuel on the same class of work. At present I have not heard of its use in this country for ordinary mixed firebrick outputs.

As to the continuous annular, and continuous chamber types of gas-fired kilns, the gas candles of the former are not by any means the best method of introducing the gas, which can be more effectively done in other ways. The chamber type must of necessity be more costly in fuel because of the additional brickwork to be heated up. There is no doubt a better distribution of heat in the chambers, owing to the position of the four combustion spaces, and it is this probably that enables rather higher temperatures to be reached.

3. Mr. Maxwell states that the amount of air passing through the cooling chambers in the annular type of kiln is five times that needed for combustion. If he means five times the *volume*, he may be correct, but if he means five times the *weight*, I think he is wrong, as the cold air entering the first chamber would expand to four or five times its original volume by the time it reaches the combustion zone. In any case, for firebricks an oxidizing atmosphere is desirable, which calls for an excess of air; and further, this heated air passes on and gives up its heat to the bricks in the further chambers, finally passing to the chimney at a temperature of about 150° C. As this is about the most effective temperature for chimney draught, it would seem that although the heating up of the excess air in the first instance absorbs heat from the cooling bricks, this is given up again to the other bricks, so that it merely serves as a medium for transferring the heat, and cannot be considered to cause a loss.

4. Although I have said so much about the annular kiln, on the principle "Speak well of the bridge that carries you

over," I do not wish to be thought to decry the tunnel and car type. There are great possibilities about it, and, though I do not think it can offer a very large margin in fuel consumption, I certainly do think that it would give appreciable economies in the heavy work of setting and drawing, and if the heated air, which in this type of kiln usually goes to waste (in Mr. Dressler's kiln he states it as high as 50 per cent.), were used to dry the green bricks in preparation of the kiln, a further economy would result.

Without more data than Mr. Maxwell has given us it is not easy to make a full comparison. Possibly he can tell us what would be the length of the pre-heating zone, the burning zone, and the cooling zone, necessary for a kiln to burn about 300 tons of firebricks to a temperature of 1,300° C. weekly. It would also be interesting to know what rate of travel is the best in the case of bricks of about 100 cubic inches, and blocks of about 1,500 cubic inches, because obviously goods of such different mass could not be soaked completely through in the same length of time, unless the bricks were in the burning zone very much longer than they actually needed to be.

As I understand kilns of this type have been used chiefly for pottery or earthenware, where the mass of the articles is relatively low; to be suitable for the heavier and thicker goods turned out in an ordinary firebrick works a tunnel of about 300 metres would appear to be required. Possibly Mr. Maxwell can tell us more on these points.

Mr. J. W. GARDINER:—May I just say that the author of this paper perhaps intended largely to talk to firebrick rather than silica brick manufacturers. I should be very glad if he would tell us whether silica bricks have been burned successfully in them. My experience, extending over a number of years, was that gas firing was not suitable for silica, and therefore I am rather curious to know from Mr. Maxwell whether these kilns have been successful for this class of manufacture.

Mr. JAMES DUNNACHIE, Junr. (Glenboig):—I quite endorse Mr. Maxwell's views as to the superiority of gas firing over coal firing, and I have often wondered why fireclay manufacturers have been so reluctant to adopt it.

At Glenboig we have been using gas-fired kilns for forty years.

I am in agreement with Mr. Maxwell that for burning highly refractory goods the continuous chamber kiln is preferable to the tunnel kiln, owing to the better control of the speed of the kiln.

I can't say I like the idea of the burning gases descending through perforations in the floor. These perforations would, I think, be liable to get choked up with dust and sand.

This method also takes away from the strength and I much prefer a solid bottom in the kiln.

Mr. Maxwell advocates the introduction of the gas at four different points. This seems to me to be a disadvantage, and I prefer the gas to enter at one point, as there is much better control over the mixture of gas and air by this method, also draught.

The gas ought to enter by the floor of the kiln and combustion should be completed before the gases come in contact with the goods.

I don't see how this can be achieved by the method adopted by Mr. Maxwell.

The disadvantage of carrying the gas considerable distances in the flue constructed outside the kiln can be avoided by carrying the gas flue down the centre between two rows of kilns.

What Mr. Maxwell describes as the kiln of the future, namely, the tunnel and car kiln, is one which I have not had intimate experience of, but from observation it seems to me that as the fires enter each side, and the draught being lengthwise, that the goods on the outer sides of the cars will get more burning than the goods in the middle of the cars.

It seems to me that this must be the result where there is only a kind of lateral draught and the fires are not compelled to pass through the goods.

The cost of this kiln with a great number of expensive bogies must make it considerably more expensive than a chamber kiln.

Another important point seems to be the question of repairs.

It is obvious that if repairs to building or mechanism should be required the whole kiln would require to be shut down.

Mr. B. MOORE:—I can give a little information with regard to one question. It takes a long time to do even a slight repair if the kiln has to be cool. It means that it will be out of use for a fortnight or more at least.

I disagree entirely with what the author says with regard to town gas. In the future I think it will be largely used both for muffles and furnaces.

Mr. THOS. LINSTRUM (Leeds):—I have listened with very great interest to Mr. Maxwell's paper, and also to the subsequent discussion by several members, particularly with regard to the question of the gas-fired tunnel and car kiln. It is to be regretted that Mr. Maxwell is not present in order to deal with the criticisms on this type of kiln in regard to its suitability for the production of high grade refractory goods, and also to reply to the points raised by some of the members as to where and under what conditions this kiln has been used on refractory bricks, etc.

I do not hold any brief for Mr. Maxwell, but I happen to know something about these kilns, having come in contact rather closely with most of those built by Mr. Maxwell's company in this country, especially in connection with the engineering side of the proposition, and with your permission I may possibly be able to shorten the discussion and throw a certain amount of light in certain directions in which further information has been asked for.

The gas-fired tunnel and car kiln is practically a new innovation as far as this country is concerned, though I am informed that the system has been in use largely on the Continent for many years, and I believe it is the fact that the kiln has been used in some Continental works for the production of refractory goods. I know all the kilns on this principle which have been erected in this country—and they are few. I think I am correct in stating that in each case the kilns are used principally for burning stoneware pottery, and this is certainly the case in all kilns erected by Mr. Maxwell's company. Three of these kilns have been built within the last few years, one in Manchester, another in Liverpool, and a third smaller one in South Staffs. In the three cases named the goods are put into saggars for burning, and the temperature of firing, which is usually about cone 9, is not by any means so high as that necessary for the efficient burning of high grade refractories.

Now here I think you have a very essential difference of conditions, first in lower temperature firing, and secondly in the length of time required for properly finishing the goods. In the case of refractories a much longer period would be necessary in the hottest zone of the kiln, and this could only be accomplished by either materially lengthening the kiln, which would be costly, or very materially retarding the progress of the cars in their passage through the kiln, which would affect output.

It is obviously impossible to set firebricks or silica bricks on the cars in saggars, and with the size of cars used in the

larger kilns erected it is possible that there might be some difficulty in getting uniformly burnt bricks in the centre of the setting, and I feel quite sure that it would be necessary to considerably modify the size of the tunnel and also reduce the size of the cars if entire uniformity of burning is to be obtained.

A question has been asked as to where the tunnel gas-fired kiln is in operation on refractory bricks, and Mr. Jones has also referred to the burning of dolomite in this type of kiln. As I have previously stated, all the kilns in this country operating on the tunnel system are used for stoneware pottery and pottery ware generally, and I think I am correct in saying that the only work in the shape of burning refractories carried out in this country has been of a purely experimental basis, so that unfortunately there is no reliable data available. I was principally responsible for the test on dolomite, which was made in the Liverpool kiln, and I have had a sample of the dolomite burnt in this kiln. The sample has every appearance of being thoroughly calcined, but the burning of a few pounds of the material as an experiment and the burning of regular large quantities might be very different matters, and whether the larger output could be dealt with at the temperature required and produced on commercial lines is another consideration.

What I want to make clear is this, the tunnel and car gas-fired kiln has not yet proved its suitability for the highest grade refractory bricks in this country at any rate, and whilst I must not be taken as being in any way antagonistic to the kiln, I rather question whether its future lays in the direction of refractory materials. More possibly that future lays more in the direction of the pottery trade generally. Perhaps Mr. Maxwell's description of this type of kiln as "the kiln of the future" for silica and firebricks and similar goods is rather optimistic.

Personally I have a much higher opinion of the continuous gas-fired kiln for producing high class silica and fire-bricks, and materials of this description for use in steel works, gas works, coke ovens, and similar work, and this latter type of kiln has been demonstrated practically with highly satisfactory results.

Mr. G. W. MOTTRAM:—Mr. Maxwell's claim for silica brick burning is open to question. Cold air must be kept away from the bricks, and the kilns are sealed as soon as the firing is finished, to exclude the air until the bricks have cooled. In this type of kiln this would interfere with the

necessary preheating of the air for combustion, and I fail to see how the difficulty can be surmounted.

While on this subject of kilns, the question of the use of heat insulation, in the construction of kilns, would form a very useful subject for discussion.

Mr. G. H. TIMMIS:—The author in this paper condemns types of kilns Nos. 1 and 2. As regards No. 3, I should like to know if there is any kiln in work to-day of this description burning the ordinary running patterns of fireclay goods? There would be constantly passing through the kiln on some of the cars large lumps weighing from one to several hundredweights each, and they require several days both to heat up and cool down. The speed of these cars would regulate the total output of the kiln, and it seems to me that the number of kilns required for a works of any size would be very considerable. In my own case, I find it necessary to have sufficient ordinary kilns for at least five weeks' output. Perhaps Mr. Maxwell could give me some information on the subject.

Mr. J. G. MAXWELL:—I cannot understand how it is that Mr. Timmis assumes that I condemn the types of kilns No. 1 and 2. On the contrary I consider all three types of kilns excellent kilns, but in my paper I merely pointed out the advantages and disadvantages of all three types. It is of course obviously not to my advantage to condemn any one type, as I have designed and constructed here in England all three types.

There is, unfortunately, in my opinion, no perfect type of kiln, neither is there any one kiln which is suitable for any and every kind of refractory goods or other ware.

As regards the suitability of the tunnel and car kiln for burning, as I understand from the letter, lumps varying from one to several cwts each, it is quite obvious that the very large lumps would take a much longer time both to fire and to cool off, than the smaller lumps, and the speed of the cars holding the smaller lumps would be delayed in their passage through the kiln by the cars holding the very much larger lumps.

Of course it is not essential that all the goods passing through a tunnel and car kiln should be exactly of the same size or weight, but of course there is a reasonable limit in the difference in weights which it would be practical to burn different kinds of goods.

Of course if the output of a works were sufficiently large in various classes of goods to warrant the use of several tunnel and

car kilns there would be no difficulty in the matter. If, however, this were not so, then my opinion is that the tunnel and car kiln would not be a suitable type of kiln for goods of very varying weights. In cases where it is required to burn lumps of such varying sizes as one to several cwts. the No. 2 type of kiln, viz.: the gas-fired chamber type kiln, would be the most suitable type of kiln, as the large size lumps could be put into one chamber, and, as the supply of gas can be regulated to each chamber, the goods in that chamber can be fired very much heavier than in another chamber filled with a lighter description of goods. The division walls of the kiln also enable the fire to be held on to any one chamber as long as may be necessary to complete the burning.

If you will kindly refer to my paper you will observe that I did not claim that the tunnel and car kiln was capable of burning every class of refractory ware, I merely said that in my opinion it was suitable for most kinds of refractory ware.

As regards any tunnel and car kilns being at work on ordinary running patterns of fireclay goods, there are no tunnel and car kilns, as far as I am aware, erected in England burning ordinary fireclay goods. These kilns are at present burning stoneware goods, and the mere fact that it so happens that the stoneware people have been the first to adopt this kind of kiln is no proof that the kiln is incapable of burning any other kind of goods. Before we erected these kilns for burning stoneware no doubt the same argument would have been used, "Where is such a kiln to be seen burning stoneware?"

I may say from my knowledge that the tunnel and car kilns erected here in Great Britain are the only tunnel and car kilns burning stoneware in existence. On the Continent, as far as I am aware, the tunnel and car kilns were used for burning ordinary brick, firebricks, and glazed bricks, and also, I believe, sanitary ware, and the first tunnel and car kiln erected to burn stoneware in this country was an absolutely new departure.

As regards glazed bricks, I believe that the tunnel and car kilns at Delafon's works turn out some of the finest glazed bricks made, at least Mr. Oates, of the Leeds Fireclay Co., who visited these works on a tour of the Ceramic Society, informed me that the results obtained could not be better, and the only suggestion that I can make to prove that the tunnel and car kiln can burn goods other than stoneware is to burn these other goods in these kilns, and two of my clients, I know, are always willing to carry out any reasonable tests as regards this.

IV.—General Organization of Firebrick Works.

By G. Wink Wight, C.A. (Glasgow).

THE General Organisation of a business manufacturing firebricks may be conveniently referred to under four heads or departments:—

(1) Works or Manufacturing Department, which comprises the getting of raw material, processes of manufacture, handling of manufactured products until despatch from works, and erection and maintenance of works and plant.

(2 Commercial or Sales Department, which comprises all the machinery for selling the manufactured goods, purchasing goods and stores required for manufacture or upkeep, arrangements for despatch, railway carriage and shipments, and correspondence connected with manufacture, sale, and despatch.

(3) Financial and Book-keeping Department, which deals with the records of goods purchased and sold, issue of invoices and statements, receipt and payment of monies due to or by the business, payment of wages and other oncost charges, banking transactions, and the general finance of the business.

(4) Secretarial and Statistical Department, the department of the chief Executive Officer responsible to the Directors for carrying out the general policy and orders of the Board and the requirements of the law, and including the obtaining and recording information and statistics relative to the working and progress of the business.

Works or Manufacturing Department.

This department naturally comes first and is of greatest importance. If the manufacturing is wrong it is useless to run

the Commercial, Financial, or Secretarial Departments. The Manufacturing Department may be sub-divided thus:—

(*a*) Raw Material.
(*b*) Works and Plant.
(*c*) Methods of Production.
(*d*) Workers and Control.

Raw Material.

Just as the Manufacturing Department is of the highest importance to a successful business, raw material is the principal factor in contributing towards success in manufacturing. Nature has been liberal in scattering throughout our island valuable mineral deposits which the cunning and skill of man has discovered and practically utilised. Among these the clays hold a position of great and increasing importance and value. Dr. Mellor states that the term Ceramic is supposed to have been derived from Keramos, the Greek word for potter's earth, or articles made from burned clay. The Ceramic or clay working industries quite properly include everything made from clay, covering among their branches the manufacture of ordinary building bricks, tiles, pipes, sanitary goods, pottery material, firebricks and other refractory material. The uses of clay are large and varied, and just as the clays in the different districts widely differ, so do the purposes to which they may be practically applied. The manufacturer of firebricks has no use for china clay, and the maker of building bricks takes only a passing interest in fireclay, but each manufacturer is, or should be, keenly interested in his own raw material, its natural conditions and physical properties, its variations from that of his trade competitors, and the utilization and improvement to the utmost of what Nature has given him.

Every firm's representative has the same story to tell users and possible buyers—his bricks are among the best, if not *the* best on the market, and suitable for every purpose. If the clay is of good quality, and the bricks fairly well made, it is not difficult to get a fair share of the trade in the market. If a manufacturer is making a profit, and his bricks sell well, he is not too keenly interested in the purposes for which they are used. They are supposed to suit every possible purpose, and are turned out like penny pies and boxes of patent pills. Bricks sell because they are really suitable for many purposes, but often sales are made on account of the personality of the seller or his representative, and preferences of the bricklayers.

If a doctor is called in to treat a patient he seldom sends a box of patent pills, or a bottle of some medicine extensively

advertised. He diagnoses the case, and prescribes what is most suitable and calculated to give the best results. He studies his patients, the results desired, and the medicines to be applied. Only when he has full knowledge of all three does he attempt to prescribe. In the manufacture and sale of firebricks too much is left to chance by both maker and user.

The manufacturer ought to know his material thoroughly, its analysis, physical properties, changes through alteration of conditions and processes, and the effects of the action of air, water and heat. He should be able, if possible, to control the raw material at every stage until the finished article is complete. He should be thoroughly acquainted with the uses to which the material is to be applied, and be able to vary it according to the requirements of the users. The practical and successful manufacturer should spend much time in the Iron, Steel, Chemical, Gas, or other works where refractory material is used, watching his material being built in and used under varying conditions. He should work hand in hand with the user. His object should be to supply only material of the highest standard suitable for the particular purpose and calculated to last the longest possible time. By doing so, he may sell fewer bricks to each firm, but the reputation established would, in the end, bring him many customers.

The users of firebricks and other refractory material ought to have the closest possible relations with the manufacturers, if they are to have the very best results from the use of material. They should themselves study the material supplied to them, watching it at every stage, recording the dates when it is built in and taken out, the conditions of use and actual working results. They should open these records to the supplier, consult with him and encourage him to do his utmost to attain to improved results and fresh records. As a doctor is called in on account of his skilled reputation and not because of the smallness of his fee, so should the refractory material manufacturer be encouraged to give of his best at a price with a reasonable margin of profit. Too long has the vogue for cheapness been the fashion in Britain, buyers squeezing makers to a low margin and makers keenly competing for business hardly remunerative, taking it perhaps to prevent competitors getting in and hoping that it may come out right on the general turnover.

The war has effectually stopped meantime everything cheap, and in the process of adjustment the old conditions have given way. The manufacturers of firebricks in common with many other trades are making profits larger than those obtained for many years and there are opportunities at present of doing

things which could not be attempted in the past. It is true that in many cases Excess Profits duty has to be paid, but expenditure on improvement of material and processes and the turning out of improved products as well as on research is legitimate and strongly to be advocated.

It is well known that the Germans had gone far ahead of us in their methods in the firebrick and refractory material industry prior to the war. They studied raw material thoroughly, analyzed and experimented with the utmost patience, controlled each stage of manufacture and turned out exactly what they expected to attain. About five years ago, while studying German methods, I had conversations with a number of German chemists and practical experts connected with Coke Oven Plant. They all appeared to be of one opinion in comparing British and German firebricks and other refractory materials. The Germans considered that in many cases our natural resources were superior but our methods inferior. In Germany they had more research, a more highly trained technical staff, frequent analyses, close study of raw material, better equipped and systematically arranged works and plant, control of material in process of manufacture, a fuller knowledge of the requirements of consumers and greater certainty of results. A German chemist connected with a firm of worldwide reputation told me that his company preferred to use firebricks of German origin because they could rely on every brick being absolutely alike. In his opinion we might turn out a good brick but it was to a large extent by rule of thumb, and the probability of variation was infinitely greater. While not fully accepting such views there is much truth underlying them, as however good our raw material and skilful our foremen and workers we cannot as a rule fully control material at every point, and avoid variations from time to time. Some of the difficulties which beset the path of the manufacturer who desires to turn out material of a high and unvarying quality may be referred to.

Material from Pit.

A constant supervision is required over the hutches filled, both below and above ground. A miner paid by tonnage is tempted to fill his hutches in the easiest way and dirty or inferior clay, ganister, coal, and ironstone balls may be hidden under apparently good clay, and cause infinite trouble, expense, and loss both of money and reputation. Much can be done by the Pit Manager underground, by the men at the pithead, and by the vigilance of the Works' Manager and his sub-foreman in charge of the mills. Hutches may be identified and miners

dealt with by dismissal or reduction of pay. In these days, however, miners are so independent that every excuse is made for stoppage of work, and neither the Pit Manager nor the firm can afford to lose a single miner and consequent loss of output, if it can be avoided. Bad material is sometimes not discovered until the bricks are burned. The problem is then whether to let the bricks be despatched or ruthlessly scrap them. The latter is the honest, if expensive, course for the firm, but it may save loss of reputation. It is doubly difficult to put into practice if the goods are in great demand and have been promised for a particular date If possible it is better to keep them back and only supply what is satisfactory, and if necessary to consult the user and show him that his interests have first consideration. Great attention also requires to be given to the variations of material in the pit as the working of the seams proceeds from point to point. I regard it of great importance to have a laboratory and a chemist constantly examining, analysing, and criticising the material, and in close touch daily with the Pit Manager and the manufacturing departments. Only in this way can a great reputation and successful results be obtained. It is a matter of regret that so few firms in this country have been able to attain to what would be regarded in Germany as absolutely essential. We are unwilling, and often cannot afford, to spend money on research work and scientific methods, and yet it is certain that the results would justify themselves and pay handsomely in the end.

These notes on the subject of raw material and the application of scientific methods may be summed up by a plea for the support of the Societies such as the Ceramic, and for the foundation and extension of Technical Schools connected with the clay and allied industries. Exceedingly good work has been accomplished in the past by the Technical Schools carried on at Stoke-on-Trent and elsewhere, by the research work of Dr. J. W. Mellor and others, by the discussions of the Ceramic Society, the Faraday Society, and by the dissemination of knowledge and practical experience through the publication of these Societies' TRANSACTIONS. Manufacturers are also indebted to the publishers of the *British Clayworker* and the *Brick and Pottery Trade Journal* for valuable and suggestive articles by J. W. Mellor in connection with the industry. In my opinion the clay working and allied industries are only in their infancy. There is a vast field for enterprise on scientific and organised lines. We must organise, associate, and federate against the foreigner rather than against one another. Our attitude towards competitors should be to assist each other to economise our National resources. The material of each of

our manufacturers should be used where it is most suitable, in exchange for a fair financial return. We should contribute financially and otherwise to the promotion of scientific research, and to whatever is essential to the progress and success of the clay industry.

Works and Plant.

Next in importance to good raw material is well designed and arranged works and plant, otherwise many difficulties will arise, resulting in loss of efficiency and higher manufacturing costs. If the proposition is to lay down complete new works and plant, it is comparatively simple if certain principles are kept in view. Few, however, have this opportunity. Many have the more difficult proposition of planning improvements and additions to old works, and plant originally laid down with little thought of future extensions. Among these difficulties may be the necessity of extending a railway siding blocked by buildings, millhouses, mills and engines scattered at various points instead of concentrated together, insufficient headroom for shafting, elevators, and overhead delivery of material, insufficient storage accommodation on railway banks, steam carried distances in unsuitable pipes with leaky joints, and a variety of worn-out plant unduly pressed.

Planning New Works.

In planning new works and plant the following suggestions occur to me:—

(1) Prepare plans with great care before any work is done on the ground. Consider thoroughly the scope of the business, the material, and approximate quantity to be manufactured and handled within a definite period of time. Prepare a scheme for one unit embracing all that is required to turn out and handle satisfactorily and economically the quantity of material desired. Let the scheme be capable of easy expansion by the addition of another unit from time to time. Work on broad lines, looking well ahead, and endeavouring to forsee probable extensions. Leave plenty of room for extensions provided efficiency is not seriously curtailed by doing so.

(2) Choose a site for works convenient to the pit, but as near as possible to the railway, and with plenty of room for siding and loading accommodation.

(3) Plan the works so that the processes of manufacture follow one another systematically from point to point

by the shortest possible road. Let the material flow from the pit to the breakers, the breakers to the mills, the mills to the brick machines or moulding stoves, the moulding stoves to the kilns, and the kilns to the waggons.

(4) Get the plant most suitable for dealing with the particular raw material. Clays differ considerably, and the plant suitable for some clays may not be so for others. As a rule avoid second-hand plant, especially boilers, engines, and pan mills.

(5) Eliminate hand labour wherever possible, use mechanical haulage and conveyors. If practicable, deliver material from the working face by a mine in preference to a pit shaft. Carry it direct to picking tables for cleaning, from picking tables to breakers, and from breakers to hoppers above mills, and feed mills from hoppers. By use of well-known modern devices, in connection with steam and electric power, considerable saving may be effected.

(6) Concentrate grinding mills at point most convenient to serve the moulding stoves.

(7) Get the best available continuous kilns. Study to get the utmost out of the fuel, and to use it in the best possible way. Consider the utilisation of waste heat.

(8) Plan working levels carefully so as to ease the running of bogies and barrows. Make good roads to kilns and in yards and loading banks. Give overhead covers for workers wherever practicable. Provide shelters, meal rooms and decent lavatories.

These notes might be considerably elaborated. The principal object in planning works and arrangement of plant should be ease in handling material and consequent cheapening in oncost, combined with full control over every process of manufacture, and consequent efficiency in production and a high standard of product.

Methods of Production.

Plant and machinery and methods of production are obviously very closely associated. The general methods of production do not vary materially in one firebrick work from another. It is important that advantage be taken of recognised improvements, and that a progressive policy be constantly maintained.

One of the most important directions in which to look for improvement is in the control of material in process of manufacture. In the past, very few businesses have attained to the German idea of controlling material absolutely, and not only reaching a high standard of production, but producing finished material of unvarying quality. The raw material should move on from point to point in course of manufacture in such a way that it may be cleaned, mixed with other materials, and altered in composition and form at the will of the manufacturer. He should know approximately the composition and physical properties of the material at each stage, and be able to stop the process at any point desired. The plant should be designed with this end. Mechanical and automatic devices for handling should be adopted wherever practicable. It should not be left to men to mix material by putting in a given number of shovelfuls of one material to so many shovelfuls of another. The material should be accurately measured and delivered mechanically. If it is material to be mixed in a pan mill, it can be delivered from above through a shoot from boxes or accurate measures previously filled.

It has already been suggested that material coming from the pit should be passed over a picking table or tables for the purpose of eliminating ganister, ironstone bullets, etc., from clay. In the same way ganister should be watched for the prevention of mixture with clay and foreign substances.

If the clay can be weathered, it will be easier and quicker to grind, and save wear and tear of mills. Against this, is the trouble and cost of laying down material, and lifting it again, and the ground required for this purpose.

In many works the clay is brought direct from the pit, and tipped beside the dry pans, into which it is shovelled by hand-labour. This is loss of time, of economy of labour, and of wages. There is danger of breakage to the mills caused by lumps of hard material entering the pans, as well as excessive wear and tear. The clay is more easily and quickly ground when it has been shattered in a breaker. It should be delivered either direct from the breaker into the pan mill, or from the breaker to hoppers, which supply the mills as required.

In some works, dry pan mills and wet mills are run on the same shaft. If run on one shaft, the speed of the dry mill will be restricted to that of the slower going wet mill, with loss of output, and mills may require to run empty at times, with loss of power and extra wear. Mills ought to be separated out on counter-shafts, so as to run each mill separately as required, and at the proper speeds.

Elevators should be erected at the most suitable angle, so as to carry the largest quantities without spilling the buckets.

Screens are very satisfactory when made of steel sheets. The angle at which they are hung will regulate the fineness of the particles passing through them. Care should be taken to secure a uniform distribution of the clay on the screen by means of a mechanical spreader, or by a sloping plate, set across the screen. The clay should not fall on to the screen, but on to a dead plate, at the top of the screen.

A liberal supply of grog or broken bricks should be kept convenient to every dry pan mill, and mixed with the clay in process of grinding. This will keep the clay open and improve the bricks.

If men at wet mills are paid by piece work, a close supervision is required to see that the material to be used for moulding is sufficiently tempered. There is a strong temptation to give the material insufficient time in the pan.

Brick machines are used extensively for making firebricks. It was at one time considered that the best firebricks could only be made by hand. The shortage of hand labour caused by the war, has compelled many firms to extend the use of machines, and with satisfactory results. Bricks turned out of a machine have good straight edges, and bricklayers naturally prefer them in building. They are apt to be denser and slightly heavier than hand-made bricks of the same size. The secret of a good brick made in a machine lies in preparation, tempering and mixing of the clay, and in the pressure used in moulding it. The aim should be to attain as nearly as possible to the same conditions as those moulded by hand.

The makers of brick machinery would do well to consider the further adaptation of brick machines to the moulding of firebrick material into special shapes and sizes. There is a large field for enterprise in this direction, and it is certain that much might be done by combination between the makers of machinery and manufacturers of refractory material. The necessity has been advocated of bringing makers and users of firebricks into close association. In the same way brick machine makers and manufacturers of refractory material should be more closely associated, for their mutual benefit.

Very careful attention should be given to the pattern or mould shop in which are prepared the moulds for all the various sizes and shapes of material. The preparation of moulds is work of great importance, requiring extreme accuracy, skill, and intelligence, in order that the proper allowances are made for contraction in burning. There is room for skill in making moulds which will turn out the material by the best and simplest

methods, thus saving moulders' time, and wages to the firm. Moulds should be of the best material and workmanship, or the bricks will be adversely affected.

Moulding stoves should be lofty and airy. The construction of the floors is of the highest importance. They should be thoroughly well built, evenly laid, and heated by exhaust steam from the engines. The heat should be controlled in every section, as special material must be dried very slowly. Floors should be carefully swept before fresh material is laid down. Best results will be obtained in moulding stoves by a gentle heat under the floors and plenty of fresh air to carry off the moisture.

It is an advantage if the roads from the drying stoves to the kilns are on a slight slope, as this eases the running of the bogies or trucks. These must have good springs.

The subject of kilns is a large one, and can only be referred to in passing.

The present waste of coal is enormous, and is a national loss of most serious importance, which must be stopped at the earliest possible moment. The kiln of the future will undoubtedly be a gas fired continuous kiln. It is strongly to be advocated that instead of manufacturers of refractories maintaining secrecy regarding matters such as this, they should endeavour to evolve jointly the type of kiln most suitable for the material of each district. Let the rivalry between them be as to which firm shall produce the best article from the same type of kiln. Under present conditions the points to be aimed at in connection with kilns are:—

(1) Low fuel consumption.

(2) Saving of time in firing without sacrifice of quality.

(3) Keeping the plant going steadily, and preventing kilns standing idle, with consequent loss of heat.

(4) Maintaining repairs and upkeep, and thereby efficiency.

(5) Good setting and burning of material in kilns, so that steam escapes, and material is properly and thoroughly burned, and such defects as black cores avoided.

If loading banks and railway sidings are roofed in there are obvious advantages:—

(1) Material kept dry. It is well known that bricks absorb moisture, and not only cost more in railway carriage, but deteriorate in quality from exposure. This should be kept in view by the users also, who should put the bricks under cover as soon as received.

(2) Work can be carried on in bad weather, thus avoiding delays and stoppages.

(3) It will save the workers from ill-health and discomfort, and result in steadier and better work.

Workers and Control.

Presuming that the raw material is good, the works systematically laid out on a well arranged plan, equipped with first-class plant, to be run by the best modern methods, the further problem is to find a capable staff and experienced workers. If they are well treated the gathering together of good capable workers is only a matter of time. It is clear that the old conditions under which labour has worked are passing away. The workers are no longer satisfied with the rates of wages formerly in vogue, and are demanding a much larger share of the price obtained for the goods they have assisted to turn out. They are also insisting on very different conditions of work. Those who come closely in contact with the average British working man know that he is not difficult to lead if left to himself, but he will not be driven. Difficulties often arise through the interference of Trade Union officials, and when agitation and unrest begin they are most difficult to stop. The aim of the management and foremen should be:—

(1) Keep the work going whatever happens. If it stops oncost charges continue to run on.

(2) Give each man the work most suited for him. Encourage him to take an interest in it for the credit of himself and the firm.

(3) Make the conditions under which each man works as comfortable as possible. Give him the best plant and tools available, and every facility for doing work well.

(4) Pay good wages for good steady work. Make the men feel that if they will assist in making a success of the business they will share in such success both by better pay and improved conditions.

(5) Encourage men to feel that they are part of the concern and bound up with it. Discourage men from leaving one work for another without good reasons.

(6) Make men understand that they are considered and will be well treated if they work well, and that just grievances will be rectified, but that under no circumstances should work be stopped. Treat them considerately but firmly, on the principle of the iron hand in the velvet glove.

Heads of Departments.

The following scheme for control of departments in a firebrick work is suggested:—

A.—*Works Manager or Chief Foreman.*

He supervises and controls manufacture and execution of orders, and is responsible to the general manager or managing director. He has under his charge the following departments:—Under departmental managers or foremen and sub-foremen.

(1) *Milling Department* (A) in which material is cleaned, crushed, ground, elevated, screened, milled, tempered and delivered to brick machines or moulding stoves for manufacture of special and normal bricks.

(2) *Milling Department* (B) in which material is crushed, ground and despatched in wagons in bulk or in bags and casks for home and export trade.

(3) *Moulding Department*, in which the bricks are moulded from the plastic material and dried on the floors

(4) *Kiln Filling, Setting and Emptying.* This work is usually done by contract.

(5) *Kiln Burning.* The chief kiln burner is usually responsible for the efficiency of the burning.

(6) *Yard and Despatch Department.* This includes loading, packing and tallying wagons, storage of goods in yard and on loading banks, emptying coal wagons and keeping kilns supplied with coal, etc.

(7) *Pattern or Mould Shop* in which the moulds are made or altered in accordance with drawings and specifications, and issued to moulding stoves.

(8) *Crate, Barrel and Bag Shop*, in which crates and boxes are made, altered and prepared, barrels coopered, and bags stencilled and got ready.

B.—*Pit Manager.*

His duty is to keep the Works supplied with raw material. He is responsible for methods of working in the pits, the safety of the men underground, and the regulations of the Mines Acts.

C.—*Engineers and Boiler Department.*

The Chief Engineer is responsible for erection and upkeep of plant and machinery of every description, for the running of the plant, and the supply of steam or other motive power. He controls

(1) Boiler firemen for steam raising.

(2) Engine and machinery fitters and oilers.

(3) Blacksmiths and tool shops.

D.—*Works Upkeep, Repair and Extension Department.*

This department is under a master of works or works upkeep foreman. His duty is to erect and renew buildings, roofs, gutters, kilns, roads, loading banks, seats for boilers, engines and mills, dispose of ashes from boilers and kilns, supervise stables and cartage. He has the assistance of the necessary bricklayers, joiners, slaters, carters and labourers.

The formation of a works' council, consisting of the heads of departments, is strongly to be recommended. Meetings should take place at intervals for the general discussion of matters affecting the working of the department.

Commercial or Sales Department.

This is the department which is probably best organised in most businesses. If goods are not bought and sold well, the business will make slow progress. The principles to be kept in view are as follows:—

(*a*) A good commercial manager responsible for enquiries, quotations, orders, commercial correspondence, shipping and railway arrangements. He should be in direct touch with works and execution and despatch of orders, and with the firm's agents.

(*b*) Agents giving whole or part time to the firm's business, paid by salary or commission, working in the various districts from which business can be profitably obtained.

(*c*) Lists of customers and prospective customers in each district. These can well be kept on the card system and systematically scrutinized to see if old customers are falling away or new customers obtained.

(*d*) Promptitude in executing and despatching orders, and accuracy in carrying out the instructions of customers.

(*e*) Extreme care and courtesy in dealing with every person brought into contact with the business.

Financial and Bookkeeping Department.

This department is also as a rule well organised and well managed. A very useful paper might be given on the methods of keeping books and records, internal checking of goods coming in and going out, and of invoices and statements, tabular bookkeeping, cost accounts, etc.

Secretarial and Statistical Department.

This is a department which is well worth organising and developing.

From the information and statistics gathered by this department daily, weekly, monthly, and yearly, the general manager, or managing director, should be able constantly to feel the pulse of the business. Figures are not everything, but in their own cold way they may convey many home truths. If properly and systematically recorded, they may be the index finger arresting us at one point, and pointing us on at another.

The following suggestions for the keeping and studying of statistics may be found useful:—Pit output—Rule a sheet with 12 vertical columns, marked along the top with the 12 months of the year, January to December. Take 31 lines running across the sheet and work at the left-hand side from top to bottom, the numbers 1 to 31 representing the days of the month. Get a note each day from the pit of the output, and insert the figure in its proper column, representing the day and month of the year. Thus on 1st October the output from the pit may have been 523 tons 11 cwts. of clay, and on 2nd October 550 tons 7 cwts. Insert these figures in black ink in their respective places, and show the daily totals in red ink. By this means there is seen at a glance the output from the pit on any particular day, the total output for the month, and at any date in the month, and the corresponding totals across the page for every other month.

A daily scrutiny will give the manager a good idea of the pit output, and how it is affected by various accidents and conditions, whether it is keeping pace with the requirements of the works, and what the prospects are for the future.

If more than one class of material is taken out of the pit extra columns can be inserted in the sheet, or separate sheets

kept for each material. If output is not maintained the manager naturally wants to know the reason for the deficiency, and will at once take steps to deal with the matter, and to press for increased output.

In the same way a sheet may be ruled to show the monthly and yearly outputs, for the purpose of comparing the monthly totals with each other and with previous years and at any particular period of the different years.

Brick Machine Output. By the same method the output from each brick machine and from the total number of brick machines may be recorded daily, monthly, and yearly. If the daily totals are inserted in red ink, it can be seen at a glance how the output is running for the month as compared with previous months.

Output from Wet Pans. It is impossible to get the exact output from each pan, but it can be obtained approximately by placing a sheet daily on the wall at each pan and getting the man at the mill to mark off each charge taken out, showing separately the charges at each of the three stages of the day. This will not only tend to maintain output from the pans but will give for statistical purposes the daily output from mills. The total weight is ascertained approximately by taking the average weight of a charge.

Kiln Output. Records are kept of the exact contents of each kiln and the weights and quantities. By this means it can be seen whether the contractors are keeping back the proper filling of any kiln, as also the quantities being manufactured and passing through, and the comparison with other periods. Further records are kept of each kiln, the dates of filling, burning, cooling, emptying, and any idle days, with the object of keeping them constantly in use.

Coal Used. The tickets taken off coal wagons are marked to show whether the coal is used at kilns or boilers, and handed into the statistical department. A daily record is kept of each coal wagon coming in, its number, name of colliery, weight of fuel and distribution.

The totals for each month are transferred to a sheet showing the total coal used at kilns and boilers in weight and value. By this means any month in any year can be compared with another. This information also forms a part of the costing system.

Wagon Output. One of the most important records for a manager is the daily despatch of material sold. It is of vital importance to the business to maintain and increase sales and

despatches, both in weight and value. Just in the same day as the records are kept daily and monthly for pit and other output, so the daily output of wagons may be recorded, both in number and weight, and value of contents.

Other Statistical Records.—The writer has designed and put into practical operation a large number of forms designed to elicit at a glance a variety of information of great value to the conduct of firebrick businesses. These include information as to wages paid under various classifications, departmental outputs and costs, classification and analysis of daily sales in weight and value, showing carriage and average price per ton realized at works for normal bricks, special bricks, and different classes of ground material, etc.

This information is calculated to show up constantly the progress of the business, and to give warning of any backward movement, so that the cause can be immediately ascertained and dealt with.

Other useful forms relate to requisition by departments for stores, issue of enquiries and orders for stores, recording of incoming stores in stock books, time records, stock records, purchasing records, etc. When once in operation, these records are easily kept, and well repay the time and trouble spent in keeping and examining them.

V.—On the Testing of Refractory Materials.

COMMUNICATIONS FROM THE CLAY AND POTTERY LABORATORY, STOKE-ON-TRENT.—No. 77.

I.—THE REFRACTORY TEST.

By Dr. J. W. MELLOR.

THE ultimate object in testing a firebrick is to determine how it is likely to behave when in use. It is assumed that the samples actually tested are fairly representative of the whole of the bricks under examination, and that the behaviour of the samples under the conditions of the test enables a prediction to be made with some confidence as to the future conduct of the whole of the bricks. In devising the tests, it is of course desirable to reproduce as nearly as possible actual working conditions. A service trial accompanied by records of the furnace conditions is the ultimate test of the quality of the material, and this may be regarded as the ideal mode of testing Unfortunately, such tests would occupy far too long a time to be a useful criterion of the quality of any particular consignment of refractories. Further, contradictory reports are obtained even with service trials. It is not at all uncommon to find two works, manufacturing the same products by similarly designed furnaces, getting discrepant results from the same fire-bricks—one engineer-in-charge reports that he cannot use A's firebricks, and that B's firebricks are the only ones he can rely upon; the other engineer-in-charge reports the direct converse, B's are no good, A's are alone satisfactory. Still a third engineer will report that either brand gives good results. Of course, a very slight change in the design of a furnace may make all the difference between success and failure. For instance, I have known half-an-inch difference in the position of the tuyere-nozzles of a cupola to alter the life of the lining from a few days to as many weeks. It is also found that when tests are made on a small scale, different results are obtained; and when tests are made in the laboratories of user and consumer, under different conditions, the results are not always concordant.

Even to-day there are troubles in several trades on account of discordant analyses.

It is therefore important that the methods of conducting the tests be standardized, since a consignment might be condemned on a set of tests conducted in one laboratory which would pass the tests satisfactorily if conducted in another laboratory. I believe that *the standardization of the methods of testing refractories* is one of the first duties which should be undertaken by our Society; afterwards we can deal with *specifications for refractories.*

The fire stability of a refractory is perhaps its most important quality, and one of the most important properties indicating the fire stability of a refractory is the squatting temperature. It is very important that we have a clear idea what is meant by what is variously called the *fusing temperature, softening temperature, squatting temperature, fire stability* and the *melting or fusion point* of a refractory. I went into this question some years ago, and the results of those inquiries are recorded in the 1909 volume of the TRANSACTIONS of our Society.[1] I have very little to add to what was there developed. These results have been confirmed by work in other countries—Germany, America, etc.

1.—The Importance of Specifying the Rate of Rise of Temperature.

When the temperature of a fireclay or firebrick is gradually raised, the material—more particularly aluminous firebricks—behaves in a manner almost analogous with pitch or butter. The material becomes less and less viscous, ultimately the viscosity is so reduced that the material is no longer able to retain its shape, the angular corners and edges are rounded, and the material begins to flow. There is no precise or definite temperature above which it can be said that the material is a flowing liquid, and below which it is a rigid solid. *The softening temperature of a firebrick is not therefore a definite temperature, but rather a range of temperature within which the substance begins to lose its shape, and commences to flow.* Observation shows that this range of temperature is wider with aluminous firebricks than it is with siliceous firebricks

If the temperature be rapidly raised, the material appears to soften at a higher temperature than if slowly heated, because the internal forces have not time to attain a state of equilibrium before the material is carried to a still higher temperature.

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1 J. W. Mellor, *Trans. Cer. Soc.*, 9. 79, 1909; J. W. Mellor, A. Latimer, and A. D. Holdcroft, *ib.*, 9. 126, 1909.

Otherwise expressed, the actual squatting of the material lags behind the temperature, *and the faster the rise of temperature the greater the lag.* The effect is sometimes very pronounced. For instance, two different firebricks with a difference of 150° in their squatting temperature on a slowly rising temperature, appear to be equally refractory on a rapidly rising temperature. The softening temperature of a refractory for one rate of rise of temperature does not correspond with the softening temperature determined for another rate of rise of temperature. Consequently, the rate of rise of temperature must be standardized if refractory tests are to be compared one with another. Although this has been clearly defined in the Institution of Gas Engineers' *Standard Specification for Refractory Materials* the importance of the fact does not appear to have been grasped by all.

It has been stated above that the softening temperature of a substance is a range of temperature within which the material begins to lose its shape. This range of temperature is conveniently referred to Seger cones, which are standard mixtures of silicate materials designed to soften within certain ranges of temperature. The softening temperature is determined by heating a selected piece of the refractory material—approximately shaped like a cone or prism 1½ inches high and ½ to ¾ inch base—alongside a suitable number of Seger cones covering a certain range of temperature. When the test-piece shows signs of fusion it is assumed that the softening temperature is best represented in terms of the cone which squatted nearest to that at which the clay begins to fuse. At first sight this seems rather a primitive method of conducting the test; but, all things considered, and with all the refinements of modern science at our disposal, I do not know a better way.

2.—*Definite Temperatures versus Seger Cones.*

Is it better to express the softening of a refractory as a definite temperature determined by means of a pyrometer or in terms of suitable cones? So far as I can see, in the present state of our knowledge, the answer must be given in favour of cones. It must be remembered that we are dealing with a range of temperature, not a specific temperature. Whatever be the nature of the reactions which are attended by the fusion of the refractory, it is assumed that the temperature coefficient of the reaction in the Seger cone and clay are the same. This assumption is based on more or less remote analogy between the cone and the clay. I must confess that when I am told that a firebrick has "a melting point of 1,700° C.," I can attach no clear meaning

to the phrase. A lot of other information is required, and we can confidently anticipate that if others had made the test a different result would be obtained. A seller would naturally desire to have his tests made at the laboratory which gives the highest result, and a buyer at the laboratory which gives the lowest result. I believe that the representation of the softening temperature of a clay in terms of a definite temperature gives an appearance of accuracy to the results which is quite illusory. I am reminded of an adventure of Gulliver in his travels among the Laputians. You may remember that he said:

> Those to whom the king had entrusted me, observing how ill I was clad, ordered a tailor to come next morning and take my measure for a suit of clothes. This operator did his office after a different manner from those of his trade in Europe. He first took my altitude by a quadrant, and then, with rule and compass, described the dimensions and outlines of my whole body, of which he entered upon paper; and in six days brought my clothes very ill made and quite out of shape.

3.—*The Size of the Test-piece.*

Would the refractory test be improved by using larger pieces—say a whole brick? I do not think so. There are difficulties, but not insuperable ones, in maintaining a whole brick at a uniform temperature throughout the mass, and also in estimating the temperature of the interior of a hot brick. Unless I am mistaken, the fusion of a brick always commences at the surface, not necessarily because on a rising temperature the surface must be slightly hotter than the interior, since by raising the temperature slowly enough the difference of temperature could be made negligibly small. If the arguments I gave in the TRANSACTIONS of our Society[1] in 1909 are correct the phenomenon is an effect of surface tension, and the surface of a firebrick of uniform composition uniformly heated must be the first to show signs of fusion. So far as my observations go I have not found any difference in the fusion test, whether the surface examined be large or small, provided the radius of curvature is large and the rise of temperature be not too rapid. True, with abnormally fine powders, where the radius of curvature is small, there is a marked difference, but not under ordinary conditions.

4.—*Oxidizing versus Reducing Atmospheres.*

It is well known that if a refractory material contains much iron its refractory test gives a lower result if conducted in a reducing atmosphere than if conducted in an oxidizing atmos-

[1] J. W. Mellor, A. Latimer, and A. D. Holdcroft, *Trans. Cer. Soc.*, 9. 126, 1909.

phere. The bricks are usually fired in an oxidizing atmosphere, and very frequently used in a reducing atmosphere. The test naturally should be conducted under reducing conditions, and it is perhaps easier to make the test under such conditions than in an oxidizing or neutral atmosphere. The only objection to the reducing atmosphere depends on the fact that the reduction of the iron sometimes takes a long time, and it is then difficult to get constant and comparable results. A different proportion of the iron is reduced in the different cases. This question is being treated by the Gas Engineers' Committee on refractory materials, and something definite may be expected in its next report.

5.—*Testing Refractories under Load.*

There is a difficulty in standardizing the test for refractories under load. The results are curious and particularly interesting. With the more aluminous types of refractory there is a rapid fall in the squatting temperature as the load increases. To get comparable results from test to test, for industrial purposes, it is necessary either to fix an arbitrary pressure at which the tests shall be made, or else to express the results in the form of a curve. The latter is probably the better way, although it will probably be more convenient to conventionally specify a definite load—say 30 to 50 lbs. per square inch. With aluminous refractories, there does not appear to be a limit to the decrease in the refractoriness under an increasing load. Indeed, there is every reason to suppose that aluminous bricks could be vitrified by pressure alone, and W. Spring's experiments[1] in 1884 showed that purified alumina, normally stated to melt at about 2,000°, can be melted at ordinary temperatures by a pressure of about 5,000 atmospheres per sq. cm., but neither natural nor artificial silica showed any evidence of fusion. H. Tresca[2] also in 1868 obtained evidence that dry clay flows like a liquid by the application of a pressure of 10,000 kilograms per sq. cm.

6.—*The Manufacture of Firebricks without Kiln-firing.*

The logical inference from these facts is somewhat startling; it is merely necessary to drive the water from clays, and then mould the bricks under a great enough pressure to perform the work of vitrification without firing the bricks at all. I have

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1 W. Spring, *Bull. Acad. Belg.*, (2), **45**. 746. 1878; (2), **49**. 323, 1880; (2), **5**. 220, 492. 1883; (2), **6**. 507, 1883; (3), **10**. 204, 1885; *Bull. Soc. Chim.*, (2), **10**. 204, 1885; *Ann. Soc. Geol. Belg.*, **15**. 156, 1888; *Zeit. Phys. Chem.*, **2**. 536, 1888; **15**. 65. 1894.

2 H. Tresca, *Mem. Acad. Inst. France*, **18**. 733. 1868; **20**. 75, 281, 617, 1872.

taken some trouble in the past to emphasise the fact that the vitrification changes which occur during firing are arrested by the manufacturer at a certain stage of their progress, and that a number of firings at, say, cone 4, under normal conditions, will do the work effected by one firing at cone 10. When no undue pressure is exerted, however, the reaction is arrested if the temperature be reduced much below cone 4, and no vitrification occurs. At first sight any proposal to manufacture good firebricks without kiln-firing seems to border on madness. We have become so obsessed with the idea that manufacturers of firebricks do not fire their products to a high enough temperature, that a counter proposal, say, to compress the dehydrated clays in a freezing chamber without firing appears the rankest heresy, not to be taken seriously. In spite of this, I see no flaw in the deduction when applied to aluminous clays. In practice, however, things have a way of developing differently from what logic prescribes, because we are so liable to overlook some essential factor. In the present case, the unforeseen difficulties will have to be furnished by observation and experiment. Extrapolation of the data in the paper by Capt. Moore and myself[1] gives too small a pressure for the softening of a refractory at room temperatures. I should very much like to see the experiment performed, but it would not be the first application of the idea, since I am told that over 45 years ago Mr. W. H. Turner, of Staffordshire, made vitreous pottery and actually attempted its manufacture on a commercial scale by the application of enormous pressures, and without firing. Nothing appears to have developed from the idea, but, from what I can gather, most people thought the project qualified Mr. Turner for permanent residence in a lunacy ward. I do not know how Mr. Turner was led to the idea, but I believe that in the light of what we have learned to-day, he was a bit in advance of his time. If the necessary funds were available I should certainly try the experiment "with alacrity," as Priestley used to say. The provisional assumption is made that the product formed by the vitrification of the clay will be satisfactory whether the vitrification be performed at a high or at a low temperature. We can, however, easily be lost in a labyrinth of unprofitable speculation as to what might happen. An experimental trial can alone give the empirical data required for further progress in this direction. I believe the deduction I have outlined justifies the expenditure involved in getting a fair trial. Possibly the right way to get the idea tried practically would be to place the evidence before a professional promoter of new schemes and give him the first option on possible patents. In spite

[1] J. W. Mellor and B. J. Moore, *Trans Cer. Soc.*, **15**. 117, 1915.

of the well-known admonition: *Nisi scis, noli prædicere*—do not prophesy unless you know—I will be reckless enough to predict that the result would be successful with the aluminous types of fireclay, although I do not think it would be successful in making silica bricks without a rather more elaborate preliminary treatment of the raw material than would be needed with normal fireclays. Even here, however, I believe the cost of the preliminary treatment would still keep the total cost of manufacture less than that which is involved in the present method of manufacture. The product of the two reactions will probably be different, but without trial no one can say which would be better or worse.

7.—*Some Theoretical Considerations.*

There is an important theoretical question. The results obtained by testing refractory materials under a load appear to contradict the well-known thermo-dynamic formula:

$$\frac{dT}{dP} = \frac{T}{L}(v - v_0)$$

where P denotes the pressure, T the absolute temperature of fusion, v the volume after fusion, and v_0 the volume before fusion. This formula has been verified and established by experiment. The main assumption behind this rule is the impossibility of perpetual motion; we should be justified in suspecting any conclusion which is not in accord with this rule. If the latent heat of fusion is positive, as it always is, then the raising or lowering of the fusion temperature with unit change of pressure (dT/dP) is dependent on whether the volume v of the liquid is greater or less than the volume v of the solid. If the volume of the material decreases during fusion so that $v < v_0$ the melting temperature will be lowered by pressure, and if the volume increases during fusion so that $v > v_0$ the melting temperature will be raised by pressure. Otherwise expressed, *an increase of pressure favours that state which has the smaller volume.* Ice at 0° has a larger specific volume than water at the same temperature, and consequently an increased pressure favours the water phase, and the ice melts.

The volume of most of the silicates involved in the vitrification of a brick in burning increases during fusion. For instance, the specific gravity of a sample of fireclay was 2·627 before fusion, and after fusion 2·470. This corresponds with an expansion of about six per cent. In this respect, therefore, clay behaves like numerous other silicates.[1] Consequently an

[1] G. Bischof, *Neues Jahrb. Min.*, 17, 1845; C. Doelter, *ib.* ii., 141, 1901; C. Barus, *Phil. Mag.*, (5), **35** 173, 1893; J. Thoulet, *Bull. Soc. Min., France*, **3**, 34, 1880. F. Niess, *Ueber das Verhalten der Silicate beim Uebergange aus dem Gluthflussigen in den festen Aggregatzustand*, Stuttgart, 1889.

increase of pressure should raise, not lower, the fusion temperature of the clay. It has been assumed that the latent heat of fusion L is constant. Experiment shows that this assumption is generally valid, although Tammann[1] and others have discussed the possibility of the latent heat of fusion changing from a positive to a negative value. Tammann has also shown that since a liquid is usually more compressible than a solid, a positive value of $v - v^0$ will diminish with an increase of pressure, and, after passing through zero, will gradually assume an increasing negative value.

I do not think that the discrepancy between theory and practice is to be attributed to either of these possibilities, rather is the formula not applicable to the case under discussion. Theory assumes that the pressure is uniformly exerted in all directions, whereas the interstices between the grains of a firebrick would give the pressure the character of a shearing stress. The solid and liquid phases do not therefore suffer the same increase of pressure. Roozeboom[2] has shown that if V_S and V_L,

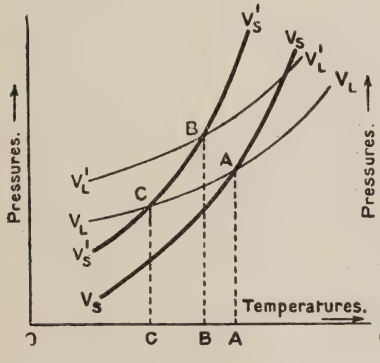

Fig. 1.

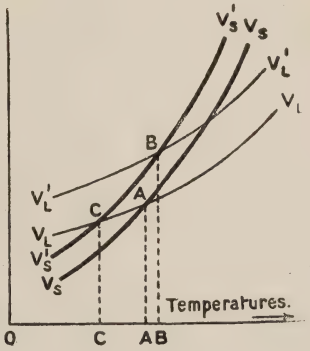

Fig. 2.

Figs. 1 and 2, represent the vapour pressure curves of the solid and liquid states at a pressure P, and V'_S and V'_L represent the vapour pressure curves of the solid and liquid at a higher pressure, when the two phases—liquid and solid—are subjected to the same pressure, the point of intersection A of the V_S and V_L curves will represent the melting point of the substance under a pressure P; similarly, the point of intersection B of the curves V'_S and V'_L will represent the melting point of the

1 G. Tammann, *Kristallisieren und Schmelzen*, Leipzig, 162, 163.

2 H. W. B. Roozeboom, *Die heterogenen Gleichgewichte*, Braunschweig, 1. 213, 1901; E. D. Williamson, *Phys. Rev.*, (2), **10**, 275, 1917; J. Johnston. *Journ. Amer. Chem. Soc.*, **34**, 789, 1912; J. Johnston and L. H. Adams, *Amer. Journ. Science*, (4), **35**, 205, 1913; J. Johnston and P. Niggli, *Journ. Geol.*, **21**, 602, 1913.

substance under a pressure higher than P. When the solid phase alone is subjected to the increased pressure it will melt at the point of intersection C of the V_L and V'_S curves. The temperature OC is always less than OA whether OB be greater or less than OA. Consequently, *the melting point of a solid will always be lowered when the pressure acts on the solid but not on the liquid.* E. Rieke[1] calculates that by the application of a pressure P,

$$\text{Lowering of melting point} = \frac{vT}{2LE} P^2$$

where E represents the elasticity of the solid in the direction of the applied pressure P; L, the latent heat of fusion; T, the absolute melting point, and v the specific volume of the solid.

DISCUSSION.

ARTHUR A. KNOX (Glenboig):—Being myself a chemist I have listened to Dr. Mellor's paper with particular interest, and to me it has been most instructive. Dr. Mellor referred to the difficulties met with in carrying out practical tests with firebricks due to contradictory reports and the length of time occupied before one could arrive at any judgment as regards the quality of the material. It is as he remarked not uncommon to find two works manufacturing the same products in similarly designed furnaces getting discrepant results from the same brand. In most cases, however, this is due to the difference in the working conditions—the temperature not always under control, different qualities of gas, variation in composition of the flue dust, the formation of the various silicates, etc., and other outside influences all going to shorten the life of the bricks.

I was very pleased also to hear his reference in regard to the standardization of the methods of testing refractories. Great differences in results are often got between those who are working daily with certain raw materials and those who test the same materials occasionally. It would be very valuable to have a book compiled containing a list of "standard methods" in testing as used in all the important technical industries. Chemists would when testing material out of their ordinary work be sure that the method they were using was the same as that employed by the chemist in that particular industry.

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1 E. Rieke, *Wied. Ann.*, **54**. 731, 1895; H. le Chatelier, *Zeit. Phys. Chem.*, **3**. 335, 1892.

Dr. Mellor's remarks on the softening point were of paramount importance. It is not uncommon to get material of the same average composition and melting point giving different results when subjected to identical working conditions. Very frequently it is due to the fact that in one case the average composition is uniform throughout, while in the other the average is made up of different compositions.

The most interesting feature in the paper was the part dealing with the aluminous clays and their vitrification under pressure. I would like to refer to a matter of interest in connection with some aluminous clay.

The Scotch fireclays of a highly refractory quality have not been very successful even when specially prepared and made into blocks for the glass industry. Little pieces of the brick getting into the glass only flux with the greatest difficulty. Some time ago two blocks *A* and *B*, of a highly aluminous clay of similar composition and melting point, were made from the same seam of clay. In a glass furnace *A* was not at all suitable, while *B* gave most gratifying results in every way, the block wearing evenly away and dissolving in the glass with ease. As the clay was treated the same in each case it was at first difficult to ascertain the reason for such varying results. It was noticed that the clay from which *B* was made was lighter in colour and had only 7·84 per cent. of combined water, while *A* had 10·34 per cent., and at a temperature where the ordinary bricks would be white and soft *B* was hard burned. Evidently the raw material at this particular part of the seam had undergone a physical change, thereby making it suitable for this particular use. The clay was got at a depth of about 200 ft., and it could be seen that there had been a geological interruption, everything indicating at this point there had been great pressure as seen from the heavy mass of whinstone forcing itself through the other beds on the top of the clay. This partial calcination of the clay may be related to Dr. Mellor's observations as regards aluminous clay and vitrification under pressure.

Mr. Wm. Donald:—Dr. Mellor's paper has been of great interest to me, as I am sure it must have been to all the brickmakers present.

In addition to standardizing the methods of testing refractories, I think there is another duty that the Society might undertake, and that is the standardizing of the reports of these tests. Take one instance, that of the average chemical composition, which is the oldest test we know, it would be of great assistance to those reading reports if the volatile matter

was expressed as a loss per cent. and the analysis in all cases was given of the fired sample. One has only to be comparing six or eight published reports to know how desirable it would be if the comparison of all these reports could be made without constant calculation eliminating the moisture, the CO_2, or whatever the volatile matter is.

With regard to the firing of kilns (apart from their testing) I would like to point out that there are three factors to be taken into account: (1) the rise of temperature, (2) the rate of that rise, and (3) the burning atmosphere. It is usual to regard the oxidizing or reducing atmosphere as only affecting the iron present in the bricks; but I think that it should be recognised how greatly it varies, and I believe that it is the change of atmosphere that has to account for variations that seem so unaccountable in the firing records. Not only are there variations in individual kilns during their firing, but there are great variations of atmosphere in each type of kiln. This is proved by firing bricks made from the same material and of the same analysis, and comparing those burned in one type of kiln with those burned in other types. There are two types of kilns in particular that I know about in which magnesite bricks are burned. One leaves the bricks almost lemon in colour and the other almost cinnamon brown. The cinnamon colour is produced in less time and is right through the brick, as is the lemon colour in the other. That can only be due to variations of atmospheres, and the pyrometer cannot register that change as it can the rise and fall of the temperature, and it is probably for this reason that the pyrometrical records obtaining in one works with one type of kiln are different from those obtaining in a second or third works with other types of kilns. I believe that if the knowledge we have or can command was applied in any works with any one type of kiln constantly at work firing one material a continuous recording pyrometer could give much better guidance than Seger cones. If there are two types of kilns very probably the two sets of records would be noticeably dissimilar.

In the future I believe that designers of kilns for the highest refractories will give the matter of the control by continuous pyrometrical records a first consideration, and I shall not be surprised if special outlets are provided so that samples of the atmosphere from the burning goods can be withdrawn periodically during the firing when there are varying records that have to be understood.

Mr. C. W. THOMAS:—Dr. Mellor has, in this paper, raised a question that is of the greatest importance both to users

and to makers of refractories. Unless, and until, a standard series of tests, with all the factors rigidly specified, is laid down, it will not be possible to make any accurate comparison of materials, nor to ascertain the suitability, or otherwise, of any particular material, or mixture of materials, for a specified purpose.

From the maker's point of view the tests should comprise the following:—

1. Fusion point.
2. Chemical analysis.
3. Petrological analysis.
4. Shrinkage, at various furnace temperatures.
5. Porosity.
6. Plasticity.
7. Resistance to load: (*a*) cold, (*b*) at various furnace temperatures.
8. Resistance to the action of certain fluxes, as occurring in industrial furnaces.
9. Resistance to abrasion.
10. Behaviour in various gaseous atmospheres under furnace conditions.

I venture to say that there is not a single maker who would not be glad to know what his products were capable of in each of the directions named, and I think the same might be said of users also.

1.—*The fusion point* is important in that it enables a preliminary classification of the material to be made, but I think it should be tested both in the oxidizing and reducing atmosphere, because the effect is different, and in most furnaces there is more or less alteration between the two conditions. The fusion point is best expressed in Seger cones, because what you want to measure is not the temperature, but the heat work done on the clay. The test should specify the size and type of furnace used, and the rate at which the temperature is raised.

2. The chemical analysis is also necessary for classifying the material. The exact method of working should be specified, though even then there will always be variations in results, especially where the work is done by a chemist who is not regularly carrying out clay analyses.

3. The petrological examination is often more instructive to the maker than the chemical analysis, because it should give him a clearer idea of the physical composition of his clay, which in many cases is a guide to its subsequent behaviour.

4 and 5. The shrinkage and porosity at various temperatures are important, and the tests should be made at a certain rate of heating up, and the temperature should be maintained for a definite length of time.

6. Plasticity is important, because on it depends the method of moulding, and also the amount of "grog" that the clay will carry.

7. Resistance to load, cold, is of course a simple crushing test, but at furnace temperatures I consider it almost the most important test of the lot. Dr. Mellor says it is difficult to standardize, but I think it might be done. Two series of tests should be made, one at 25 lbs. per square inch and one at 50 lbs. per square inch, the test piece being a standard sized brick on end, and the result expressed in terms of the percentage reduction in length from cold.

8. Resistance to fluxes is important where slag conditions have to be met with. The test piece might be a $4\frac{1}{2}$ in. cube, with a hemispherical hollow, $2\frac{1}{2}$ in. diameter, moulded in one face. The block, with the hollow filled with the required flux, should be heated at a definite rate, and maintained at a definite temperature for a specified length of time. When cooled, it should be sawn through medially, and the action of the flux studied under the microscope. The fluxes used should be representative of industrial processes, as glass, iron, steel, and other smelting processes, and chemical manufacture.

9. Abrasion tests should include a sand blast, and, if possible, not only on the cold brick, but also at furnace heats. Other industrial conditions would be best met by a test on a carborundum wheel under specified loads.

10. A refractory should also be tested for its behaviour under different gaseous conditions. Much of the destructive effect observed in modern furnaces is due to the action of different gaseous mixtures at furnace heats, and it is important to know how far it may be necessary to compromise other requirements to meet this particular one.

I am afraid I have dealt at greater length with the subject than I should, but it is of such great importance that I think it should be well ventilated. I am very glad indeed that the Section has taken this matter up, because I regard it as the foundation of any further improvement in refractories in general and fireclay refractories in particular.

When once the tests have been standardized I suggest that the Section might do worse than equip a laboratory at Stoke with such apparatus as is needed to carry out the full range of tests on a proper scale, and so establish a standard for refractory materials of all classes in this country.

Mr. BERNARD MOORE:—I remember the attempts of Mr. W. H. Turner to make dinner plates by the application of enormous pressures. They were serious attempts, and several thousands of pounds were spent in making dies and a press. The dies had to be many times altered since many unexpected difficulties arose. I have no reliable information of the pressure used, but the press was of enormous power. In the end as many as 20 plates were made at once, but after a very short run of about half-an-hour the press was broken. I do not think there was any idea of doing away with all firing, although I believe it was hoped that the biscuit fire could be dispensed with.

I do not think that it is safe to assume, as is generally done, that a reducing atmosphere always makes a refractory material fuse at a lower temperature. I think I have met with instances where a strongly oxidizing atmosphere has suddenly brought about the melting of a mass. It is of course quite common with some glazes, and I see no reason why it may not apply to some types of brick.

VI.—Study in Chrome-Tin Pink.

COMMUNICATIONS FROM THE CLAY AND POTTERY LABORATORY, STOKE-ON-TRENT.—No. 78.

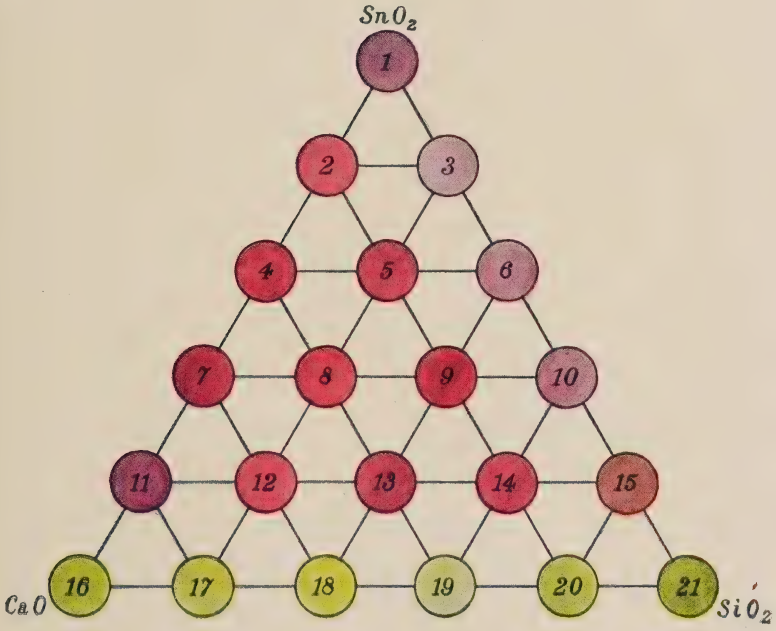
By E. W. T. MAYER.

IN undertaking a new investigation of this subject it is not my intention to dwell on the voluminous record of previous work, but to try to show with the aid of a triangular diagram the different colours obtained from mixtures of tin oxide, lime, and silica, with potassium dichromate, and from the results to fix on a good base for further work, a report on which forms the later part of this paper.

The mixtures first made up were as indicated in the triangular diagram, using the same quantity of potassium dichromate—3 per cent.—in each case. The other ingredients were present respectively in the proportions 0, 20, 40, 60, 80, and 100 per cent. All the trials were calcined in a china biscuit oven in unflinted cups, pounded up, recalcined and wet ground. It may be remarked that all these colours washed yellow, showing free chromates in solution. Those high in lime settled quickly on washing, and a scum formed on the top of the wash water. Silica colours settled slowly and were milky for some time. On drying, the colours high in lime set hard.

After drying, an attempt was made to print with the colours, which proved a failure, the plate being blinded. This difficulty was overcome by having the colours banded, and dipped in lead and leadless glaze respectively, the trials marked 1L to 21L, among those exhibited, having been dipped in leadless glaze. All the trials were fired in the glost oven—third ring. On comparing trials dipped in lead glaze with those dipped in leadless glaze the difference was found to be slight.

As the diagram shows, the colours containing no lime, viz.: Nos. 1, 3, 6, 10, 15, and 21 (this last consisting of silica only), were lilac in tint, diminishing in strength from 1 to 15; No. 21, however, was a dirty-looking greyish green. The colours containing no tin oxide, viz.: Nos. 16, 17, 18, 19, 20, and 21, were shades of light green except the last-named. The remaining mixtures, including Nos. 2, 4, 7, 11, and those



Colours produced by Tin Oxide, Lime and Silica, with 3 per cent. of Potassium Dichromate.

occupying inner positions in the triangle showed the chrome-tin pink colour.

To find a suitable starting point for a good chrome-tin pink, it seems advisable to consider particularly the mixtures occupying inner positions in the triangle. These form a small triangle with No. 5 at the apex, and Nos. 12, 13, and 14 at the base, with Nos. 8 and 9 in intermediate positions. Seger's standard falls within these limits, and it was decided to mix Nos. 5 and 9 in equal proportions. This mixture (called 59) was made up, calcined twice in china biscuit oven, wet ground, dried, banded, and dipped in lead glaze and leadless glaze respectively. To this base were added 5, 10, 15, and 20 per cent. of calcium fluoride, borax crystals, boric acid, stone, felspar, and alumina respectively, to ascertain their influence.

In the series 1A, 1B, 1C, and 1D, containing 5 to 20 parts of calcium fluoride added to 100 parts base No. 59, the increase in the amount of calcium fluoride has a darkening effect, but all are good colours. In the series 2A, 2B, 2C, 2D, with corresponding additions of borax crystals instead of calcium fluoride, all the mixtures gave rich-looking colours, as were also those of the series 3A, 3B, 3C, and 3D, with similar amounts of boric acid instead of borax, this last series (3A, etc.) being cleaner looking than 2A, etc. Similar series 4A, 4B, 4C, 4D, with mixed stone, and 5A, 5B, 5C, 5D, with potash felspar, were also tried. Series 4 (A, B, C, D) were all good dark colours. Series 5 were also good colours, lighter than series 4.

In the final series 6A, 6B, 6C, 6D, in which 5 to 20 parts of alumina were added to 100 parts of the base 59, increase of the alumina inclines the colour towards rose pink.

Considering the low percentage of tin oxide (42) in the D mixtures, they are all good colours.

VII.—The Effect of Magnesian Glazes on Underglaze Colours.

COMMUNICATIONS FROM THE CLAY AND POTTERY LABORATORY, STOKE-ON-TRENT.—No. 79.

By C. P. SHAH.

IT has been generally understood that the presence of magnesium oxide in earthenware glazes has a detrimental effect on the production of underglaze colours. Knowing that no systematic work has been done on the subject by any member of our Society, Dr. Mellor suggested to me the advisability of making a few experiments in this direction. He said:

> It has been long known to potters that magnesium compounds—steatite, etc.—exert a fluxing action on glazes and bodies. In the old days magnesium compounds were regularly employed as constituents of the body, and even to-day there are bodies containing the equivalent of magnesium oxide up to 18 per cent. It has also been stated that magnesite bricks are objectionable for frit kiln bottoms because the frit dissolves enough magnesium oxide from the bricks to make the glaze subsequently spoil the underglaze colours. It is therefore of importance to find by preliminary experiments what deleterious effects magnesium compounds exert on normal underglaze colours.

It is true that magnesian glazes have been mentioned by Ramsden, H. Wicks and Dr. Mellor, and Perry,[1] but these experiments were made for different purposes altogether.

In order to investigate this subject three glazes were made up in accord with the following composition:

I.—MAGNESIAN GLAZE.

$$\left.\begin{array}{l} \cdot 3\,(KNa)_2O \\ \cdot 4\,PbO \\ \cdot 2\,CaO \\ \cdot 1\,MgO \end{array}\right\} \cdot 2\,Al_2O_3 \left\{\begin{array}{l} SiO_2\ 2\cdot 5 \\ B_2O_3\ \cdot 5 \end{array}\right.$$

FRIT.

Stone	58·2
Flint	95·1
Boric acid	62·0
Whiting	18·0
Potassium nitrate	25·654
Soda ash	13·462
Magnesium carbonate ...	8·4
	280·816

MILL MIXTURE.

Frit	221·8
China clay...	25·8
White lead	103·2
	350·8

1 Ramsden, XII, 256, TRANS. E.C.S.; H. Wicks and Dr. Mellor, E.C.S. TRANS., XIII, 61, and Perry, XIII, 71.

2.—LEAD GLAZE.

$$\left.\begin{array}{l} \cdot 207\ Na_2O \\ \cdot 065\ K_2O \\ \cdot 385\ CaO \\ \cdot 335\ PbO \\ \cdot 006\ MgO \end{array}\right\} \cdot 247\ Al_2O_3 \left\{\begin{array}{ll} SiO_2 & 2\cdot 799 \\ B_2O_3 & \cdot 354 \end{array}\right.$$

Frit.		Mill Mixture.	
Borax	195	Frit	400
Flint	109	Stone	250
China clay	37	Flint	100
Whiting	100	White lead	250
Stone	100		1000
	541		

3.—LEADLESS GLAZE.

$$\left.\begin{array}{l} \cdot 560\ CaO \\ \cdot 224\ K_2O \\ \cdot 148\ Na_2O \end{array}\right\} \cdot 548\ Al_2O_3 \left\{\begin{array}{ll} SiO_2 & 3\cdot 412 \\ B_2O_3 & \cdot 944 \end{array}\right.$$

Frit.

Whiting	56
Felspar	125
Flint	85
China clay	84
Soda ash	16
Boric acid	117
	483

The colours used were all made under practical working conditions, and consisted of greens, Victoria greens, blue greens, blue, matt blue, browns, yellow, orange, fawn and black, and the numbers ranging from 2 to 43.

I do not intend to read recipes for all these colours, but a number of typical recipes I have put on the board.

Trials marked as *L* indicate lead glaze. Trials marked *LL* indicate leadless glaze, and those without any mark are from the magnesian glaze. These trials were fired in a Dressler tunnel oven on open trucks, and the firing temperatures were 1,100° C. to 1,120° C. measured by Seger cones.

Series A.—BROWN.

No.	9	41	42	43
Zinc oxide	50	32	32	29
Iron oxide	15	34	18	23
Potassium bichromate	35	34	—	—
Chrome oxide	—	—	22	11
China clay	—	—	28	37
	100	100	100	100

No. 41 sepia brown tends towards the ordinary light brown. Nos. 42 and 43 are only slightly affected, but No. 9, the light brown, is almost destroyed. The main difference between No. 9 and No. 41 is that the No. 9 is high in zinc oxide and low in iron oxide as compared with No. 41. Increasing zinc oxide evidently causes the marked difference.

SERIES B.—VICTORIA GREEN AND GREENS.

No.	5	6	25	27	28
Fluorspar	—	20	—	—	10
Flint	22·75	22	30	24	31·5
Whiting	22·75	20	—	—	20·5
Potassium bichromate	41·00	38	—	—	21·5
Calcium chloride	13·50	—	—	—	—
Borax	—	—	18	43	—
Zinc oxide	—	—	18	12	—
Soda crystals	—	—	9	—	—
Chrome oxide	—	—	20·6	15	—
Red lead	—	—	—	—	9
Plaster	—	—	—	—	7·5
Cobalt oxide	—	—	4·4	6	—
	100	100	100	100	100

Victoria greens are completely altered in tone, the typical pea-green tint being absent. All colours in this series are rich in lime, and this, I think, accounts for the change in colour. Colour No. 25—an olive green—is also changed, whereas No. 27 is not altered.

I have repeated the experiment with Victoria green by aerographing the colour to get a better body of colour on, and, as you will notice, the effect is very marked.

SERIES C.—PINK AND CRIMSON.

No.	16	31
Tin oxide	71	59
Whiting	24	30
Flint	4	4
Potassium bichromate	1	3
Borax	—	4
	100	100

This series is very interesting as it bears out the statement made by Mr. Ramsden in volume XII, p. 256 of TRANS. E. C. S., "Of all the basic oxides used in glazes magnesium oxide exerts the most detrimental effect on crimson colours." These colours are entirely destroyed. The pink is completely altered, what little colour is left being very slight in tint.

SERIES D.—BLUE AND MATT BLUE.

No.	18	37	29
Alumina	—	—	50
Cobalt oxide	68	75	25
Stone	17	19	—
Flint	12	—	—
White lead	3	6	—
Zinc oxide	—	—	25
	100	100	100

Magnesia has no effect on this series. Unfortunately the matt colour No. 29 is somewhat heavily glazed, and this prevents the true effect being seen.

SERIES E.—BLUE GREENS.

No.	8	20	21
Cobalt oxide	26	25	25
Chrome oxide	8	40	50
Alumina	66	20	—
Felspar	—	5	—
Zinc oxide	—	10	25
	100	100	100

These three colours, though widely different in composition, are not altered materially, though slight difference in shade is observed in Nos. 8 and 21.

SERIES F.—BLACK.

No.	17
Cobalt oxide	32
Nickel oxide	13
Iron oxide	36
Manganese oxide	12
Chrome oxide	7
	100

This colour is greatly improved and is much denser in tone.

SERIES G.—YELLOW, ORANGE AND FAWN.

No.	2	4	24
Red lead	34	47	—
Antimony oxide	25	28	—
Felspar	22	13	—
Tin oxide	11	6	56
Iron oxide	8	—	14
Zinc oxide	—	6	14
Lead chromate	—	—	16
	100	100	100

None of these colours are strong colours when printed, and so I have aerographed them also. Magnesia has no effect

on yellow and orange, while the fawn is altered when printed, and no material change when aerographed is observed.

SUMMARY.

Series No.	Colour	Effect
A ...	Brown	Increase of zinc oxide destroys the colour The tints of browns are altered
B ...	Victoria greens	Change of tint altogether
	Greens	Modification of tint
C ...	Pink and crimson	Colour is destroyed
D ...	Blue and matt blue	No effect
E ...	Blue greens	Slight difference in shade of colours
F ...	Black	Improves the tint
G ...	Yellow and orange	No effect
	Fawn	Destroys the colour when printed

Possibly if colours made on the triaxial bases were used, more direct evidence as to the behaviour of magnesium oxide would be obtained, but it was thought advisable for a start to keep to practical recipes.

I am much indebted to Dr. Mellor and Mr. W. Emery for suggestions and help on various occasions.

DISCUSSION.

Mr. F. S. WORTHINGTON:—Was anything in the way of ruckling or other roughness, or peeling, observed in the case of the matt blues?

Mr. C. P. SHAH:—No ruckling or peeling was observed.

Mr. A. HEATH:—Was anything beyond ·1 MgO present in any glaze tried? It is understood that a low percentage of magnesia increases the brilliance, but a larger proportion—say more than ·2 MgO—destroys the colour.

Mr C P. SHAH:—No more than ·1 MgO was used.

VIII.—The Effect of Pressure on the subsequent Contraction, Tensile Strength and Crazing of Tiles.

COMMUNICATIONS FROM THE CLAY AND POTTERY LABORATORY, STOKE-ON-TRENT.—No. 80

By E. WATKIN.

IT is well known that the working properties of tile and other bodies made in dies are considerably modified by the pressure. Messrs. Foster and Emery[1] recently measured the effect of pressure on thickness and porosity of a body, and, since this is merely one aspect of the question, Dr. Mellor suggested that I pursue the subject still further. I have therefore investigated the effect of pressure on the contraction and the tensile strength of the body, and on the behaviour of the glaze.

An ivory body was used with the following composition :—

Ball Clay	...	25
China Clay	...	32
Flint ...	...	28
Stone ...	...	15

The body was ground to dust, damped, and passed through a 10's lawn. An average sample contained 9 per cent. moisture. The same amount of dust was used in making each trial, and each trial had its own particular pressure put on twice, *i.e.*, after getting the pressure once, it was released and then applied again. The trials were fired together in a biscuit oven to a temperature represented by Watkin's Heat Recorder No. 27, approximately cone 5A.

The porosity and thickness of each trial were measured, and the results obtained confirmed the previous experiments made by Messrs. Foster and Emery, viz. : "That porosity and thickness decrease with increasing pressure."

The statement, "The greater the pressure, the less the thickness," does not hold good for a constantly increasing

1 W. Emery and J. E. Foster, *Trans. Cer. Soc.*, 15, 143, 1916.

pressure, as there must be a pressure at which the minimum thickness is obtained, and any increase then in pressure will not affect the thickness, but will only result in spoiling the article. It may be sufficient here to say that this limit is not reached with the machine used, which registers 4,000 lbs. pressure, which is equivalent to 1,220 lbs. per square inch.

1.—Contraction.

The effect of an increasing pressure upon the contraction is shown in Table I, and these results are plotted in Fig. 1. The results obtained do not agree with those obtained by Messrs. Foster and Emery, who state that: "The pressure, whether increased steadily or with bumps at the end, does not affect the ultimate linear contraction," but show that "The greater the pressure, the less the contraction." A trial made with 4,000 lbs. pressure contracts 5 per cent., whereas one made with 500 lbs. pressure contracts 8 per cent.

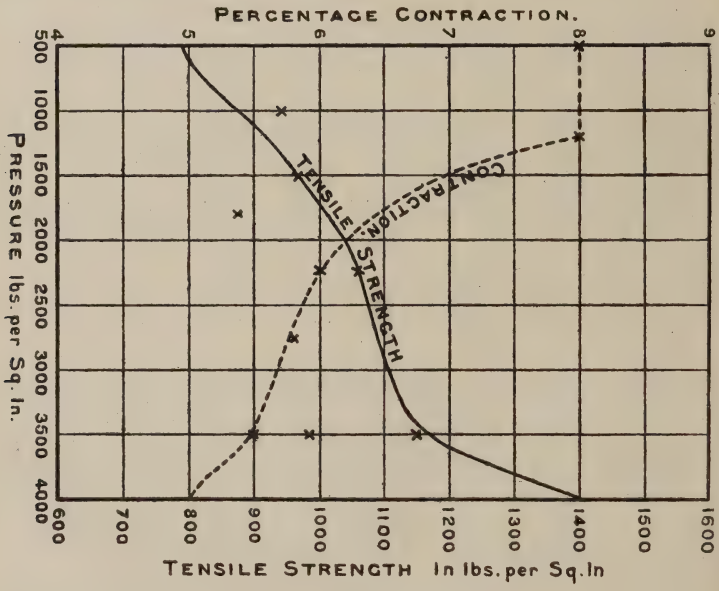


Fig. 1.

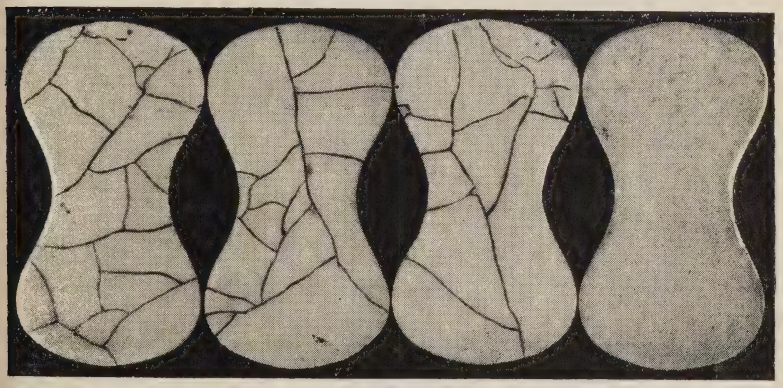
2.—Tensile Strength.

The tensile strength of the trials stated in lbs. per square inch was determined in a Faija machine. The trial is placed in two jaws, one fixed, and the other attached to a movable arm. This arm is gradually pulled away by a chain movement, the resistance being recorded on a scale.

The results obtained are shown in Table I, and a curve is plotted in Fig. 1. These results, although not so regular as one would have wished, show most decidedly that: "The tensile strength increases with increasing pressure." A trial made with 500 lbs. pressure has a tensile strength of 790 lbs. per square inch, while one made with 4,000 lbs. pressure has a tensile strength of 1,400 lbs. per square inch.

3.—The Effect on the Crazing of the Glaze.

For the purposes of showing the effect of pressure on crazing, it was found that a glaze very near the crazing point was necessary. The results (as here shown) show that the tendency to crazing is lessened as the pressure is increased. Too much importance, however, must not be attached to this



500 lbs. 1,500 lbs. 2,500 lbs. 4000 lbs.

Fig. 2.

statement, as other points must be taken into consideration, *e.g.*, "The thickness of glaze on the trial." This to a large extent is dependent upon the porosity of the article dipped, and, as the trials made with the least pressure have the greatest porosity, then we should say that they would take a correspondingly thicker glaze, and so be more liable to craze. For purposes of comparison, a trial made with the highest pressure was dipped twice in order to get a thick glaze. The result shows that it has not crazed, hence, we might say with some justification: "That the tendency to crazing is lessened by increasing pressure." With this particular body and glaze, crazing appears when the pressure is below 2,500 lbs. pressure, the crazing getting more pronounced as the pressure decreases.

TABLE I.

Pressure	Contraction	Tensile Strength	Effect on Glaze
4,000 lbs.	5·0 per cent.	1,400 lbs. per sq. inch	Not crazed
3,750 ,,	5·3 ,,		,,
3,500 ,,	5·5 ,,	(980)	,,
3,250 ,,	5·7 ,,		,,
3,000 ,,	5·7 ,,	1,150 ,, ,, ,,	,,
2,750 ,,	5·8 ,,		,,
2,500 ,,	5·8 ,,	1,060 ,, ,, ,,	Crazed slightly
2,250 ,,	6·0 ,,	1,060 ,, ,, ,,	
2,000 ,,	6·0 ,,	(850)	Gradually getting more pronounced as pressure decreases
1,750 ,,	6·6 ,,	,,	
1,500 ,,	6·6 ,,	960 ,, ,, ,,	
1,250 ,,	8·0 ,,	960 ,, ,, ,,	
1,000 ,,	8·0 ,,	940 ,, ,, ,,	
750 ,,	8·0 ,,	810 ,, ,, ,,	
500 ,,	8·0 ,,	790 ,, ,, ,,	

TABLE II.

Pressure	Porosity	Pressure	Porosity
4,000 lbs.	4 per cent.	2,000 lbs.	6·3 per cent.
3,750 ,,	4 ,,	1,750 ,,	7·5 ,,
3,500 ,,	4·4 ,,	1,500 ,,	8·7 ,,
3,250 ,,	5 ,,	1,250 ,,	9·5 ,,
3,000 ,,	5 ,,	1,000 ,,	10·1 ,,
2,750 ,,	5·5 ,,	750 ,,	12 ,,
2,500 ,,	5·8 ,,	500 ,,	16 ,,
2,250 ,,	6·2 ,,		

DISCUSSION.

Mr. J. E. FOSTER:—I am not aware of any difference in linear contraction under pressure, whether the pressure be applied steadily or suddenly. This question was not under investigation, and it is inexplicable how the statement referred to (in the last sentence of the paper by myself and Mr. Emery) got to be inserted.

Mr. A. LEESE:—The conclusion that the greater the pressure the less the crazing may be compared with the known effects of easy and hard firing of the biscuit. I cannot see why increased pressure, beyond a certain limit, should break up the piece.

Mr. E. WATKIN:—I cannot offer any explanation as to why an article should break up if too much pressure is applied, except that experience is continually confirming it as a fact, under the particular conditions by which electric and similar fittings are made.

Mr. W. EMERY:—What are the effects of increased pressure in the case of crooked tiles? How does the highest pressure used in making the trials compare with actual practice? The same pressure would be approximately 20 tons on the whole surace of a 6 in. tile.

Mr. E. WATKIN:—This question is rather difficult to answer, as there must be varying pressures according to the size of the die, the weight of the descending tool and the power behind it. It is a point which has appealed to me, and I have made a number of trials to determine the pressure exerted in making a tile 3·14 square inches. The method adopted was that of a comparison of porosities, one set of trials made in a die that measures the pressure, and another set made in the die referred to above. These trials were fired together, and then the porosities were determined. The trial of known pressure which had a similar porosity to those made in an ordinary die, I assumed, in the absence of other reliable data, to be the pressure at which the ordinary tiles were made. This proved to be in these experiments 830 lbs. per square inch.

Mr. W. SIMPSON (answering Mr. Emery):—Greater pressure results in less crooked tiles.

Mr. A. H. RYLES:—It is found in practice that with more than a certain maximum pressure articles cannot be made satisfactorily.

Mr. W. BAKEWELL:—Why is it that a trial made with 1,250 lbs. pressure and one made with 500 lbs. pressure, both having the same contraction, do not have the same tensile strength? It there any relation between the contraction and tensile strength?

Mr. E. WATKIN:—In answering the above question, we must take into account the porosity of the trials referred to. This, as we have seen before, decreases with increasing pressure, and although trials made with 1,250 lbs. and 500 lbs. pressure respectively have a similar contraction, the amount of porosity in these trials is very different, viz.: 9·5 per cent. porosity with 1,250 lbs. pressure, and 16 per cent. porosity with 500 lbs. pressure. This difference in porosity is a sufficient cause for the decrease in tensile strength.

IX.—On the Rate of Hydration of Calcined Dolomite.

By C. Edwards and A. Rigby,

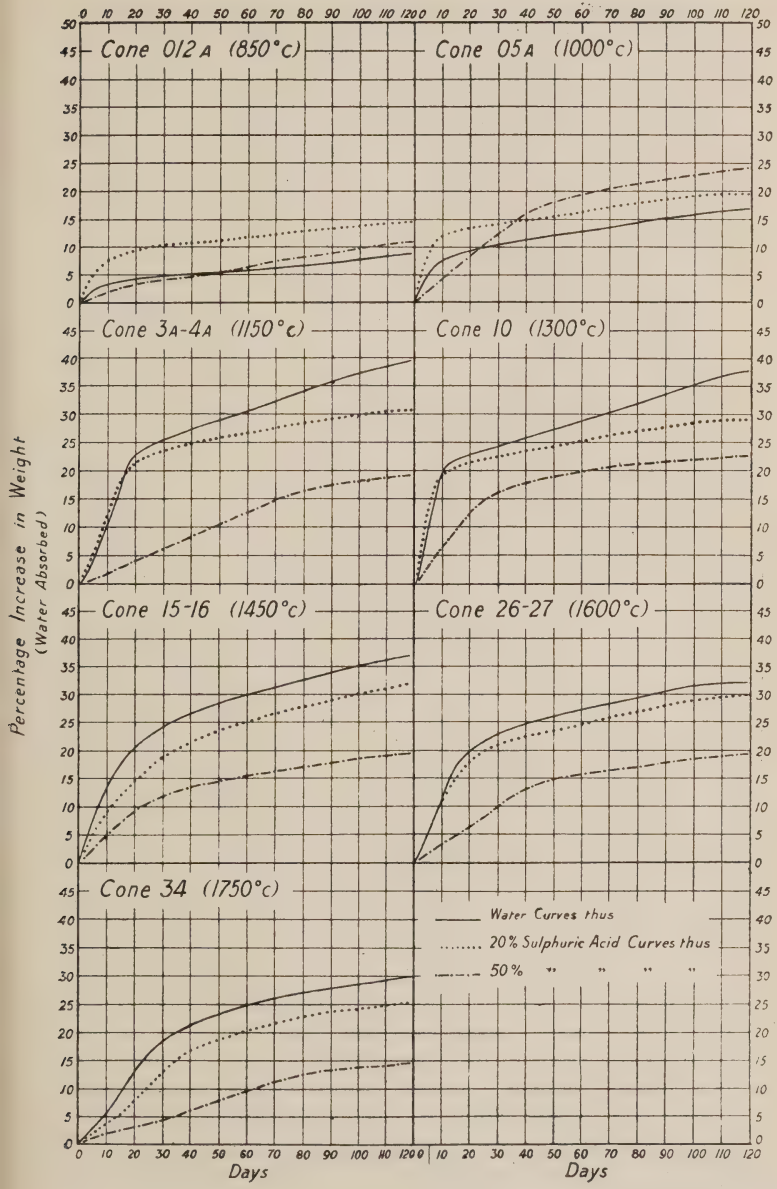
Communications from the Clay and Pottery Laboratory, Stoke-on-Trent.—No. 81.

With a Note on the Decalcification of Dolomite,

By J. W. Mellor.

Dr. Mellor suggested to us that some data on the rate of hydration of dolomite after calcination at different temperatures would be both interesting and useful. A commercial sample of raw dolomite was therefore calcined at the following temperatures: 850° C. (cone 012a); 1,000° (cone 05a); 1,150° (cone 3a—4a); 1,300° (cone 10); 1,450° (cone 15—16); 1,600° (cone 26—27); and 1,750° (cone 34).

Five grams of each sample in small glass capsules were placed in closed desiccators over atmospheres of different degrees of humidity: (*a*) water, (*b*) 20 per cent. sulphuric acid, (*c*) 50 per cent. sulphuric acid, and weighed every day over a period of 10 days. The vapour pressure of water at 15° C. is 12·7 mm. mercury; of 20 per cent. sulphuric acid at 15° C. is 11·5 mm.; and of 50 per cent. sulphuric acid at 15° C. is 4·5 mm.; 20 per cent. sulphuric acid (sp. gr. = 1·15) = 20 gm. H_2SO_4 + 80 gm. water; 50 per cent. sulphuric (sp. gr. = 1·40) = 50 gm. H_2SO_4 + 50 gm. water. The weighings, etc., of the dolomite after exposure are indicated in the following table. The results are plotted in the diagram so as to show the increases in weight which occurred during seven-day-intervals. The slopes of the curves then represent speeds of hydration. In the samples calcined at 850° and 1,000° probably all of the double carbonate was not converted to oxide. The flattening of the curve after approximately 20 per cent. hydration has occurred, suggests that first the lime hydrates fairly quickly, and afterwards the magnesia hydrates comparatively slowly.


Cone 012 A (850°c)
Cone 05 A (1000°c)
Cone 3A-4A (1150°c)
Cone 10 (1300°c)
Cone 15-16 (1450°c)
Cone 26-27 (1600°c)
Cone 34 (1750°c)
Water Curves thus
20% Sulphuric Acid Curves thus
50% " " " "
Percentage Increase in Weight
(Water Absorbed)
Days
Days

	Cone O 12 a			Cone O 5 a			Cone 3 a-4 a			Cone 10			Cone 15-16			Cone 26-27			Cone 34		
Time in Days	Water	20%	50%	Water	20%	50%	Water	20%	50%	Water	20%	50%	Water	20%	50%	Water	20%	50%	Water	20%	50%
10	3·5	8·0	2·0	7·5	12·0	4·0	11·0	12·5	2·2	20·0	19·5	6·5	13·5	8·5	4·7	11·0	11·0	3·5	5·5	3·5	2·0
20	4·2	9·0	3·5	9·5	13·5	8·5	23·0	22·0	4·2	23·0	21·5	12·5	20·5	14·5	9·2	20·0	18·0	6·5	13·0	7·5	4·0
30	5·0	10·0	4·5	10·5	14·5	12·8	25·2	23·2	6·2	24·2	22·5	16·5	24·0	18·5	11·7	23·0	20·5	10·0	18·5	12·5	5·0
40	6·0	11·0	5·2	11·8	15·5	16·0	27·0	24·2	8·2	26·0	23·5	18·0	26·5	21·0	13·5	24·5	22·5	13·0	21·0	16·5	6·0
50	6·5	11·5	6·0	13·0	16·0	18·0	29·0	25·2	10·2	27·5	24·5	19·0	28·0	23·0	14·5	26·0	23·5	15·2	23·0	19·0	8·0
60	7·0	12·0	7·2	13·5	16·7	19·5	30·7	26·2	12·5	29·0	25·5	20·0	29·5	25·0	15·5	27·5	24·5	16·5	24·0	21·0	10·0
70	7·5	12·7	8·0	14·0	17·2	20·5	32·0	27·2	15·0	31·0	26·7	20·5	31·0	27·0	16·5	28·5	25·5	17·2	25·0	22·0	11·7
80	8·0	13·0	9·0	15·0	18·0	21·5	33·7	28·2	17·0	32·2	27·5	21·0	32·0	28·2	17·0	29·0	26·7	18·0	26·0	22·5	13·0
90	8·5	13·7	10·0	15·7	18·5	22·2	35·7	29·0	18·2	33·5	28·5	21·5	33·5	30·0	18·0	30·0	28·0	18·5	27·2	23·0	13·7
100	8·7	14·2	10·5	16·2	18·7	23·0	37·5	30·0	19·0	35·0	28·7	21·7	34·5	30·7	18·5	31·0	28·7	19·0	28·2	24·0	14·0
110	9·0	14·8	11·0	16·7	19·0	23·2	38·8	30·7	19·5	36·5	29·0	22·0	35·5	31·5	19·0	31·5	29·5	19·5	29·0	24·7	14·5
120	9·2	15·0	11·5	17·0	19·2	23·5	39·8	31·0	19·8	37·5	29·0	22·2	36·5	32·0	19·5	32·0	30·0	19·5	30·0	25·5	14·5

Dr. J. W. MELLOR:—The decalcification of dolomite has attracted some attention in past years and several patents have been taken for the operation. There is no difficulty in separating the two main components of dolomite by chemical processes, but handling large quantities of chemicals would make the cost of decalcification rather high for competition with native magnesite for brickmaking, etc., after the war. The non-chemical methods of separation based on

(1) The difference in the densities of the two constituent minerals when calcined at a high temperature; and

(2) The greater inertness of the magnesite when the calcined mass is exposed to a humid atmosphere or to water

offer some attractions. In all methods of treatment the structure of the product is totally different from that of native magnesite, and this would introduce additional complications in subsequently making "magnesite" bricks from decalcified dolomite.

In following up the ideas indicated in my note on the spalling of magnesite bricks, I asked Messrs. Edwards and Rigby to find out something definite about the relative rates of hydration of samples of dolomite calcined at different temperatures.

The decalcification of the products of the calcination of dolomite by washing with water was the subject of a patent by H. Auzies and A. Segoffin.[1] The separation of 60 per cent. of the contained lime and thus raising the amount of magnesium oxide in a typical dolomite to nearly 80 per cent. MgO, has been effected by this treatment. I have also had experiments made on the pneumatic separation of the two minerals, and I hope to report later when they have been tried on a larger scale.

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[1] H. Auzies and A. Segoffin, *Brit. Pat. No.*, 1425, 1907.

X.—A Study of the Bone China Body (Part I—Colour).

COMMUNICATIONS FROM THE CLAY AND POTTERY LABORATORY, STOKE-ON-TRENT.—No. 82.

By. W. H. YATES and H. ELLAM.

IN an important and too little known paper on the red coloration of bone china, Mr. Bernard Moore[1] showed the effect of diminishing amounts of alkali or increasing amounts of clay on the coloration of bone china bodies. This discoloration appears as a serious fault in manufacture, and very serious losses have resulted, and still result through ignorance of the facts which Mr. Moore emphasized in his paper. We thought it was advisable to give a comprehensive survey of the variations in the colour of bodies compounded with all possible mixtures in 20 per cent. variations of the three primary constituents of a bone china body viewed where translucent by transmitted light.

The bodies were compounded in the usual way and (*a*) cast into cups with slip 30 oz. per pint, and also (*b*) pressed into slabs.

The trials were fired to Cone 9 in the regular china biscuit oven. The composition of the bodies is indicated in Table I, and the numbers correspond with those indicated in Fig. 1.

There is a remarkable series of tints ranging from a very pale cream or white to yellow and reddish brown, and a deep greenish-blue, as indicated (Fig. 1). The colours were matched by the block-maker from the trials which were sent to him. The colours are not quite right in some cases, but they are the best he could do. He took the colours by viewing them in a bright electric light, and they appear rather more intense than when examined in the ordinary manner.

1. In passing from the china clay apex (No. 1) to the bone apex (No. 16) in the series without stone the colour becomes brown, increasing in intensity to the deep red brown shown by the mixture with 60 per cent. of clay and 40 per cent. bone (No. 4). The colour then changes to a dirty bluish-green with 40 per cent. of clay and 60 per cent. of bone (No. 7), the mixture with 80 per cent. of bone and 20 per cent. of clay

[1] B. Moore, *Trans. Cer. Soc.*, 5, 37, 1905.

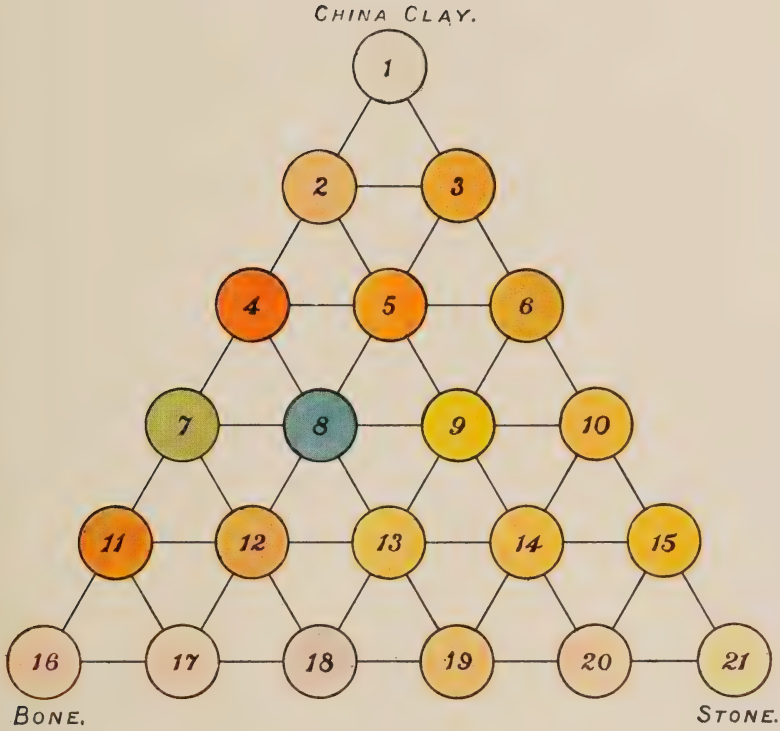

Fig. 1—The Colours of Bone China Bodies which result by varying the proportion of the Bone, Clay and Stone.

is reddish (No. 11), and with the bone alone (No. 16) the colour is pale cream. This remarkable series shows the effect of the bone on the tint of china clay.

2. In passing from the china clay (No. 1) to the stone apex (No. 21) in the series without bone, the colour is yellowish-brown. The china clay and stone alone have the paler tints.

3. In passing from the bone (No. 16) to the stone apex (No. 21) in the series without china clay the colour is gradually intensified slightly with increasing proportions of stone. The 40 of bone and 60 of stone mixture (No. 19) had the most intense colour.

4. In passing along the series with 60 per cent. of china clay (No. 4 to No. 6) the brown colour gradually becomes paler and paler and the proportion of stone decreases.

5. In the series with 40 per cent. china clay the dirty bluish-green colour of the mixture without stone (No. 7) becomes a greenish-blue with 20 per cent. of stone (No. 8), yellow with a faint blue or green tinge with 40 per cent. of stone and 20 per cent. of stone (No. 9), and becomes a pale brown (No. 10) as the proportion of bone diminishes.

6. In the series with 20 per cent. china clay the reddish-brown colour (No. 11) becomes paler and paler as the proportion decreases (Nos. 12 to 15).

Mixing with Nos. 7 and 8 with the greenish-blue colour become reddish-brown when kept for a month or two; and the colours of those trials low in stone, are also liable to turn brown if kept a few months. In the glazed trial No. 7, with the free body, wherever there is a craze the underlying body is turned brown. This shows that the development of the brown colour is due to the oxidizing action of the air. A subsequent glost fire has a tendency to clear the brown and green colours developed in biscuit, and a subsequent enamel kiln fire intensifies the colour. Table II indicates another set of results with three series of trials fired under different conditions.

All the trials down the "clay-bone" line—Nos. 1, 2, 4, and 7—were crazed. The glazed trials are also liable to craze in the neighbourhood of the greenish-blue and reddish-brown colours. The development of these colours in this set of experiments corresponds with a deficiency of stone, with a high proportion of clay. The contraction of the trials with the excess of stone are the greatest, not the least, as one might expect.[1] High stone also increases the tendency to blistering.

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[1] Contraction decreases up to 40 per cent. stone, when it increases again.

TABLE I.

No.	Clay	Bone	Stone
1	100	0	0
2	80	20	0
3	80	0	20
4	60	40	0
5	60	20	20
6	60	0	40
7	40	60	0
8	40	40	20
9	40	20	40
10	40	0	60
11	20	80	0
12	20	60	20
13	20	40	40
14	20	20	60
15	20	0	80
16	0	100	20
17	0	80	20
18	0	60	40
19	0	40	60
20	0	20	80
21	0	0	100

A description of the trials is indicated in Table II.

TABLE II.

No. of Trial	Per Cent. of Ingredients			Colour of Trial Biscuit	Colour of Trial Glost	Colour after passing through Enamel Kiln
	Clay	Bone	Stone			
1	100	0	0	Cream	Cream	Cream
2	80	20	0	Brown	Slightly paler	Brown Increased
3	86	0	20	Yellow	Shade lighter	Brown
4	60	40		Pink	Red brown	Red
5	60	20	20	Light brown	Dirty brown	Slight where glaze thick
6	60	0	40	Cream	Yellow	Brown
7	40	60	0	Green	Pale green	Still paler
8	40	40	20	Pale green	Green much increased	Brown in patches
9	40	20	40	Yellow	Yellow	Yellow
10	40	0	60	Slight brown	Slight brown	Slight brown
11	20	80	0	Brown	Shade lighter	No change
12	20	60	20	Colour very slight	Colour very slight	Colour very slight
13	20	40	40	,, ,,	,, ,,	,, ,,
14	20	20	60	,, ,,	,, ,,	,, ,,
15	20	0	80	Tinge of green	Tinge of green	Tinge of green
16	0	100	0	White	White	White
17	0	20	80	,,	,,	,,
18	0	60	40	,,	,,	,,
19	0	40	60	,,	,,	,,
20	0	20	80	,,	,,	,,
21	0	0	100	,,	,,	,,

XI.—The Milling of Potting Materials.

By H. J. Plant.

I DO not propose in this paper to deal with all the materials ground at our mills in the Potteries, but only with those that are used in the greatest bulk, and come to us more or less in a raw state. In the preparation of these materials for potters' use, cleanliness, cleanliness, and cleanliness again is of the utmost importance. Iron and dirt combined have always been a source of trouble, and only vigilance and care will enable us to keep these enemies at bay. The use of wood wherever possible, and the application of the paint brush at regular intervals will certainly help; but these preliminary precautions are only adjuncts to the use of the magnet, the picking over of some materials by hand, sifting, and the personal element of care, which can alone ensure success.

I propose to consider the following divisions point by point: Preparation and grinding of flints, stone, felspar, bone; grinding of glaze and parian; taking of trials; cylinder *v.* pan ground; final summary.

The grinding plant used will be the ordinary pan, in which the grinding is effected by the movement of heavy faced stones over a more or less flat smooth surface. The heavy grinding stones or runners, as they are called, are kept in position by an outside band of iron called the slug iron, and by the arms, which are connected up with the central driving power.

1.—Flints.

In the case of flints, it is necessary to see that the raw article is clean before putting into the calcining kiln, and that the proportion of slack and flints is regulated, so as to produce perfect calcination. This takes 48 to 60 hours. If flint is over-calcined it blisters, and if under-calcined it is difficult to grind. The best flints do not fly and shatter during calcination. After this first process, the flints are usually crushed in a steel-jawed stone crusher, which reduces them to a suitable size for charging on to the pan. In the case of cylinder ground materials the size must be much smaller than is necessary for pan grinding. Cylinder grinding was fully described in the

able paper given by Mr. Robert Shenton (see TRANS., 10, Part I, 1910—11), so that for the purpose of this paper we will discuss more fully the pan ground process. The flint should be mixed with water, and becomes a white liquid after 11 or 12 hours' grinding. A grey shade is not usually dangerous, but any pink tint should be looked on with suspicion. It should then be run into the washing tanks, which have the effect of stirring up the fine particles in suspension, and allowing the coarser unground particles to settle at the bottom. Plugs are arranged at varied depths, and the plugs are drawn when the rough material has sunk below their level. The finely ground material is run off into arks, and from thence to barrels or direct on to the drying kiln. If the flint is sent out in the slop state it is better to store same in agitated arks, as it has a tendency to settle unless this is done.

Care should be taken that the runners in the mill do not always run in the same circle, or they will work grooves in the lower stones, and when new runners are introduced they will not work down into the grooves, and the result will be imperfect grinding. Great care should also be taken in the selection of mill stones, which must have neither coloring matter nor an excess of lime in them.

The mill should not be charged too heavily at first starting, nor should it be driven too fast, or the material will not go under the stones, but be carried round with them, or forced outside the slug iron.

Only the water absolutely necessary for grinding should be used, as an excess will tend to increase the time of grinding.

Fineness can be tested by trying it between the teeth or nails, but the silk or wire lawn is always the surest test.

Blue Welsh pavers and Smith & Sons' selected chert runners provide the ideal grinding surface for flint and stone.

2.—*Stone.*

There are five main varieties of stone, hard purple, mild purple, white dry, buff, and Jersey, which possess varying qualities and differ considerably in their degree of fusibility, so that one sample will melt much more easily than another, or, in the potter's language, is "softer." From a manufacturer's standpoint very great importance should be attached to the selection of suitable qualities of stone for the purpose in view, and care should be exercised in the mixing of same, so that a standard article, having the same degree of fusibility, may be relied upon from time to time. Stone is not calcined, but is broken up, if necessary, into sizes suitable for crushing, and

after this it is charged direct on to the grinding pan, and if conditions are right 11 or 12 hours are necessary for producing a perfectly ground article. In this case again, careful washing, to separate the rougher particles is essential, and in addition to this, if the material is supplied in the slop state, ageing in the arks is usually adopted in order to obtain the correct weight per pint demanded by manufacturers.

A certain quantity of stone comes from Jersey, which is very fusible, and because of its slight pinkish tinge, which is supposed to betray the presence of iron, its value has not been fully appreciated. I suggest that it would be extremely useful in the manufacture of glazes.

Finally, stone should be carefully selected, and the aim of the miller or manufacturer should be to standardise the degree of fusibility of the ground material. In the case of dried stone it should never be burnt or overdried on the kilns.

3.—Bone.

Bone varies so much in quality, and there are so many types in use at the present time that it would be well for us to consider these types before discussing methods of preparation. Before the war, most of the bone delivered in this district for potters' purposes came from South America; the better qualities from the Rio Grande Saladeros, and the cheaper qualities, which were mostly only suitable for manure, from the River Plate district. Much of this bone had to be sent many hundreds of miles down the rivers of South America before it reached the port, whence it was shipped to England. The price before the war varied from just over £3 for the cheaper qualities, to £5 5s. for the better qualities, and while the exportation of the better qualities has now practically ceased, the price of the cheaper quality has risen to £17 per ton.[1] This bone was exported as a rule in a calcined state, and calcination was obtained in various ways. In the case of the Rio Grande, it was piled in great heaps along with wood (old packing cases, etc.), often containing nails and other doubtful properties, and the whole heap was burnt out in the open. This gave us the very valuable Rio Grande bone ash, but up-to-date methods in recovering the fats and other valuable constituents from the bone have resulted in much of this hard ash being transformed into the familiar soft calcined variety, which we are obliged to use to some extent now that the better quality is not available. River Plate ash was often obtained

[1] Early in February, 1918, it reached £20 per ton.

through the necessity of using the bone along with slack, which was very scarce, for firing the boilers. Thus it was more or less a refuse material, and this process of calcining was highly responsible for the inferior quality of the resulting article. In addition to the above qualities, we have the best shank and other bones obtained from abroad and in this country, which, owing to the greater care exercised in the handling and calcining, and the higher price obtained for same, have, as a rule, been cleaner and freer from deleterious matter. Such then is the bone which the miller is compelled to handle for pottery purposes, and it will easily be seen that great care is necessary if a good sample is to be produced from articles varying so much. The kiln generally used for calcining English bone is similar in shape to the flint kiln, but having an arrangement that causes the fumes of the fat, etc., to pass through the fire of a subsidiary combustion chamber with the idea of destroying what would otherwise be a very offensive smell, and would make calcination impossible in a populous neighbourhood. The kiln is filled with layers of bone and wood, and a fire is started at the bottom on firebars for the purpose. It takes from 8 to 12 hours to perfectly calcine the contents. The qualities of English bone may be subdivided several times, and the loss of weight by calcination of these various types varies from 16 per cent. to 60 per cent. of the gross weight. More care is probably necessary in the preparation of bone for potters' use than of any other single material, and the following process has been adopted with conspicuous success, and includes the use of the Rapid Magnetting Company's machines. In this case the bone is elevated, passed over a piano wire screen to separate the rough from the small, and each of these portions is passed over an electrically charged magnet After this the impurities, such as bits of brick, etc., not extracted by the magnet, are carefully picked out by hand. The two samples submitted show plainly the effect of each of these treatments, the better sample having been treated as above described, and the inferior sample without treatment. The original material used was similar in both cases. The dirty brown residue, looking like inferior saggar marl, was extracted from bone by the Rapid Magnetting Co.'s magnetic ore separator, a machine of recent invention, and of such power that magnetic impurities in bone can by its use be reduced to an absolute minimum. It would be necessary to use it in conjunction with the original machine before mentioned, but the resultant article would be improved immensely by the extra process, even slightly magnetic impurities being almost entirely

eliminated. Soft calcined bone treated in this way yielded about 3 per cent. of the residue. After this preliminary cleansing and picking process, the bone is charged on to the pan, water is added, and usually 10 hours is sufficient for the efficient grinding of same. Careful washing to separate out the coarser particles is as necessary in bone as in the other materials discussed, and a most important point, which should not be overlooked, is the ageing of this material, which should always be kept in arks as long as possible before pumping on to the drying kilns. This, for some reason, seems to improve the working properties of the resulting body.

Equally important is the final process, for bone should always be slowly and carefully dried. If burnt or overdried on the kiln the bone loses some of the necessary plastic qualities, will not pass through the lawns, and results in increased loss in the manufactured goods. For casting purposes overdried bone is useless. Black Welsh pavers and Derbyshire chert runners of selected quality will help in the final result by providing the ideal grinding surface.

4.—Felspar.

This article is of very great value to potters, and is used for many purposes, and for the manufacture of articles of great variety, not forgetting its value in the production of glazes. It needs careful treatment on the lines indicated for stone, but generally should be washed before crushing and grinding. Usually it takes longer to grind than stone, and should be run straight on to the drying kiln, as it would be very difficult to prevent it from setting if it was stored in the usual storage arks.

5.—Glaze.

The standard rule of testing before use should always be applied to glaze. In no other material ground by our millers is the carrying out of this rule more essential. The glaze as charged on to the pan is usually a mixture of frit with softer added materials and lead. Where the mill is not the private property of the manufacturer whose material is being ground there, very special care is needed so that the glaze mixture may not be rendered more, or less, fusible, by the charge previously ground on the pan. Sometimes a leadless glaze mixture has been so charged that it followed a rich lead mixture, and the result has been disastrous from the manufacturer's standpoint. It seems, therefore, that one type of glaze should always follow a mixture of the same type. That

is, if a glaze is leadless, it should be ground on a leadless glaze pan. It is almost impossible to clear the pan after the grinding has finished so as to avoid any chance of affecting the next charge. Again, at some mills, it is customary to grind parian body and glaze on the same pan, and I have known cases where parian body has been mistakenly used for dipping purposes with tragic results. Glaze should be well ground—sufficiently fine to pass through at least a 130's lawn—then thoroughly magnetted, and kept in storage arks as long as possible to allow it to age.

A simple method which can be relied upon to test the fineness of grinding is to dip the hand in water, and then coat the thumb nail with the glaze by dipping into same, blow the surplus off, and rub over with the tip of the finger. Another, is the same test, between the teeth, as is used for flint. If any coarseness of grain is apparent you can usually be sure that the glaze is not ready to leave the pan. Ageing of glaze is essential for the best results. It will always dip easier, and go farther than new glaze. Thus neglect on this point means consequent loss to the manufacturer.

Parian Grinding.—I may refer here again to the grinding of the parian body, which follows the same treatment very largely as is given to the glaze, and to which most of the foregoing remarks would apply equally.

6.—Taking of Trials.

I wish to discuss here the taking of trials, as it goes without saying that all materials should be tested before use as far as possible. The method adopted by myself is to cut the samples into an oblong block, measuring about 2 in. × 1 in. with a thickness of $\frac{2}{3}$ in. In the case of stone, I cut the hard purple and mild purple as above, but mark the bottom of the trials "H P" or "M P," as the case may be, and in the case of dry white or less vitreous stone, after cutting as above, I remove one of the corners, thus guarding against the samples being mixed due to the obliteration of the distinguishing marks during the firing. It is necessary to state here that stone should be covered by a biscuit bowl, and should be as air-tight as possible, in fact the same principle applies to stone as to glaze, if we are to obtain a perfect sample. Felspar is treated in the same way. No flints must be allowed to come in contact with the surface. Bone and flint should be buried in flint, but a very good plan is to mark the bone with either an inch rule or a simple marker, so that the contraction may be regularly tested. Little or no contraction

should be apparent in a good sample of bone, and generally it should cut soft, almost if not quite as soft as flint. The purer the flint the softer; hardness is only due to impurities present. To obtain regularity of results, the best place to fire trials in is below the bag in the second ring bungs.

7.—*Cylinder* versus *Pan Ground*.

This question has been so often discussed that I feel some diffidence in bringing it again forward, it is, however, of such paramount importance to the trade, that fuller consideration may lead to some useful conclusion.

For some manufacturing purposes, such as fritting, cylinder ground materials are equal to the pan ground, but I think I shall be absolutely safe in saying that the china body cannot profitably be made with materials ground in cylinders. Up to the present, as far as we know, bone has not been successfully ground in this way. As regards stone and flint, I am assured by those who have used it successfully in the manufacture of earthenware, that we should have no difficulty in overcoming ultimately the apparent loss of plasticity caused by the use of cylinder ground materials, but my own experience has shown that these difficulties may be insuperable in china. They are very real, and I may quote one personal experience which resulted in very great inconvenience and considerable loss owing to the delivery of a load of cylinder ground stone in mistake for our usual pan ground article. In a very few hours the complaints were coming in thick and fast, and the ware was splitting on the moulds in all directions, seeming to show that there is a quality of plasticity and tenacity in pan ground stone that does not apply to the cylinder ground variety. As will be seen from the samples submitted cylinder ground stone appears to be much more sandy to the touch than the pan ground article.

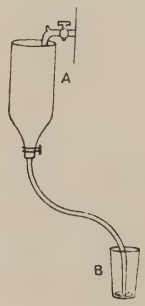
A further trial made last week of cylinder ground stone used in our casting body resulted in three out of four of the articles made splitting in the moulds, while the same body, but using the pan ground stone, was cast without any of this loss. The question thus arises, what is the cause of this difference? After close examination by the aid of the microscope and elutriation, my own belief is that there is great similarity in the shape of the particles ground on the pan and the cylinder, but in the case of pan ground material *much greater variation in size*, and a larger proportion of the very fine. The peculiarity of cylinder ground material seems to be that the particles are divided mainly into two groups—fine and

coarse—with very little of the intermediate sizes. This is confirmed by the analysis of fineness set out below.

	Cylinder	Pan
1 cm.	41·79	56·52
5 cm.	11·64	25·47
50 cm.	30·67	11·0
Residue	16·9	8·0
Surface Factors	100	131

The necessary figures have been kindly given by Mr. A. Heath, and the percentage of coarse was also confirmed by many tests made at our own works with washed and unwashed pan ground stone and cylinder ground stone.

The apparatus used is of a very simple type, as sketched below, and has demonstrated the fact that unwashed stone contains almost as much of the rougher particles as the cylinder ground stone.



The question thus arises, would not cylinder ground stone be greatly improved by washing?

In testing with the above apparatus, the vessel (*A*) contains about 3 ozs. of water, and this was kept at a constant pressure by the inflow from the tap being slightly in excess of the overflow of the vessel (*B*) containing a given weight of material. The period of time was the same in both cases, and the residue was thus easily checked.

Again, cylinder ground stone, when dried under atmospheric conditions, shows particles having no affinity for one

another, which, when touched, break up with ease in a manner similar to silver sand, whereas pan ground stone shows greater tenacity, and the particles seem to cling together in scales, or, in other words, the particles of pan ground stone seem to have a greater tendency to aggregate. This undoubted difference may be indirectly due to the method of grinding. In one case the material is reduced to a state of fineness by the crushing weight of runners, which shatters the material, and at the same time produces an abundance of minute particles, whereas the cylinder reduces the material to a state of fineness by a milder process which wears and breaks the particles, but produces in a much less degree the great variety of exceedingly minute jagged fragments obtained by the crushing effect of the runners. These minute fragments play a great part in producing tenacity, due to the fact that they are believed to lie close up to the larger pieces, filling up all cavities and intervening spaces, and creating a greater number of points of contact and suction between same. This probably solves the problem of the undoubted difference between the two resulting materials. It is a well known fact that cylinder ground material settles very much more quickly than pan ground, and I believe that this is largely due to the even size of the particles, and the absence of variation in the sizes. That cylinder ground materials are being used successfully in the manufacture of earthenware I do not deny, but a condition which may have rendered their use practicable is the fact that the lack of plasticity and tenacity in these materials is overcome by the ball clay used along with them, and which is sufficiently plastic in itself to make the clay usable. To put it in another way, the use of ball clay in an earthenware body gives a margin of plasticity which the china body has not, and, as we all know, it is very useful to have a margin. Finally, I submit as my considered opinion, that though cylinder ground materials may be adopted with success in some processes, they do not compete successfully with pan ground, where the greatest possible plasticity and tenacity is essential.

Investigation in the foregoing subjects opens up such a wide field for experiment and enquiry that I do not pretend that this paper has in any way touched anything but just the fringe. I hope, however, that it may lead to further investigation that will ultimately enable us to settle some of these controversial questions.

In conclusion, to summarize our main points, successful milling of potters' materials may be greatly assisted by care in selecting the most suitable quality in runners and pavers; careful buying of the right material; magnetting and picking

where necessary; standardisation of qualities so as to avoid difficulties for the manufacturer and workmen; ageing in arks where found to be of advantage; slow drying and not too dry; regularity and systematic taking of trials; and finally, as mentioned at the beginning, cleanliness and care in every detail.

DISCUSSION.

Mr. D. F. W. BISHOP:—It should not be forgotten that that are many varieties of bone. Soft-calcined bone presents many pitfalls for the china manufacturer, the body being somewhat shorter and more liable to produce pinholes. Continuity of grinding on a glaze pan is absolutely necessary, as Mr. Plant pointed out. If different types of glaze are allowed to follow one another trouble is sure to result. Many different flints are on the market to-day, from French boulders and mill-washed flints to the chalkiest of chalk flints, and due account must be taken of the differences.

With regard to firing trials, does Mr. Plant mean us to understand that the best place for trials—below the bags in the second ring, as stated—applies to all types of oven?

Mr. H. J. PLANT:—The statement was intended to apply more particularly to the ordinary up-draught ovens used for earthenware and china biscuit.

Mr. A. HEATH:—With regard to the firing of trials mentioned by Mr. Plant, I often think that the method of firing bone trials is wrong.

If the presence of carbon in bone is not desirable the firing of a trial by present method does not give us any indication of the ill effects, as during the firing the carbon has every chance of being burnt out of the trial, whereas when incorporated in the body the vitrifying of the surface often encloses the carbon and produces the faults attributed to carbon. I have seen many very poor samples of bone come out of oven quite as good as the very best, but the result in body was quite different.

To my mind, to get a correct trial of bone, it should be made up in a body. If, however, firing the bone alone is preferred, why not ascertain loss in weight on firing?

Mr. Plant remarked about the cylinder ground material being similar to crushed glass or sand, and not binding well in a body, and supplied me with samples of stone, so as to obtain an independent test. Owing to the time the cylinder material is kept in suspension I thought probably there had

been some addition of lime to the stone, so I got Dr. Mellor to analyse both samples:

The cylinder had 1·5 $CaCO_3$
The pan had ... 3·35 $CaCO_3$

I have heard it remarked that cylinder grinders usually add a small percentage of lime to stop the material setting. Evidently this sample has not near so much as the pan ground, and I think probably the higher percentage in the pan ground will tend to make the material bind closer together than the cylinder ground and thus give the feature Mr. Plant notes.

Mr. Plant has referred to samples of stone elutriated by me. I may say that these two samples were given me by Dr. Mellor, and he thought it would be interesting to elutriate them. On starting this process I intended to make a very full analysis of sizes, but owing to the length of time taken by the cylinder ground to clear from the 1 cm. size I had to curtail the experiment to the four sizes mentioned. The length of time the 1 cm. remained in suspension seemed to indicate that the cylinder would be very much finer than the pan, but, as you will see, such did not turn out to be the case. The fineness, as you will see from the figures, is much in favour of the pan ground.

Now this is the reverse to the results obtained by Messrs. Jackson and Lethbridge in 1902 from many samples, but I venture to suggest that at the time that work was done very little cylinder ground material was being used for bodies, hence the trials they made were taken from material ground for glazes, and consequently finer than for bodies. In surface factor the samples come out as follows:

	Jackson & Lethbridge	Plant's Samples
Cylinder	11,845, or say 1	10,058, or say 1
Pan	10,222 ,, ,, ·862	13,144 ,, ,, 1·51

Now those who had studied the effect of each grade of fineness will, I think, admit that although the surface factor may give us a very good guide to total fineness, what is of more importance is to know the effect of the various sizes and the proportions of these present.

As you know, I have devoted some little time to the study of these points, and if you refer to the conclusions I came to at the time of the work (volume II), you will find I made the following remarks:

Stone in body.—"The effect of glaze does not show any tendency to crazing, but eggshell effect and pinholes diminish with size of grain."

Stone in glaze:—"All slabs from 50 cm. gave eggshell effect, but below that grade gave nice clear surface."

Flint in body.—"With easy biscuit (Bar 23) all above 50 cm. gave eggshell, but at hard biscuit (Bar 25) this disappeared."

When Mr. Shenton read his paper I remarked that to my mind cylinder ground bodies invariably gave an eggshell appearance.

From the detailed analysis of the sample of cylinder ground stone submitted I should say that it would be very liable to produce this eggshell appearance.

To my mind the faults likely to occur from variation of fineness may be put as follows:

Pressure	...	1 cm.	Dunting.
,,	...	5 cm.	Perfect.
,,	...	20 cm.	,,
,,	...	50 cm.	Eggshell.
,,	...	100 cm.	Crazing.

I do not say you would get those results, but that the tendency is in that direction.

An approximate estimate I aim at in advising anyone on the subject of fineness in genuine earthenware body is as follows:

1 cm.	...	...	45 per cent.
5 cm.	...	...	25 ,,
20 cm.	...	...	15 ,,
50 cm.	...	...	10 ,,
100 cm.	...	...	5 ,,

Such a division, I am quite aware, involves much time in separations, but I think the results obtained quite compensate for the trouble.

Mr. A. LEESE:—With regard to cylinder ground materials not being so plastic as pan ground, my theory is, that instead of the substance being crushed between the runners and the paved bottom of the pan, the particles are rubbed off the surfaces by degrees. If this is so, the particles rubbed off and those remaining would retain their solidity as when first put on the pan.

In cylinder grinding it is generally understood the process of grinding is by the materials meeting with almost continual

concussion between the stones as the cylinder revolves, thus causing a shattering and crumbling and breaking up of the pieces.

Referring to the firing of trials: when anything is placed in the second ring the heat reaches it more slowly and gradually, and contraction takes place more steadily than in the first ring, thus giving a reliable basis to work upon as to how the materials will behave when made up in the body and placed in the various parts of the oven.

Mr. W. E. GOODWIN:—When engaged in cylinder grinding I found it absolutely necessary to add 1 per cent. of whiting. The main difference between cylinder ground and pan ground flint is that the former is seldom as fine as the latter, and it cannot be washed up on account of setting, and consequently varies in fineness. In pan ground flint there is a greater proportion of very fine material, whilst with the cylinder it is more uniformly fine or coarse as the case may be. Lawning is a great source of trouble. A man lawns cylinder ground flint at 26 or 27 oz. instead of 30 oz., when not under immediate supervision, simply because it is easier to lawn. When I personally attended to the sifter, and passed the material through at a given weight to the pint, I found very little difference.

Trials are regular with pan ground materials. With cylinder ground materials trials are not always the same, though they always came right when I lawned.

As regards stone, I never had the least trouble in connection with setting, etc.

I knew of a pan-mill where the elimination of all lime, as far as practicable, was tried, with the results that the flint set in the troughs and barrels, and even in the arks, and it was necessary to get the customer's permission to put milk of lime in before he could deliver to the factory.

It is much easier and cheaper to put up a cylinder mill than a pan mill. There is little difference in the cost of grinding to equal degrees of fineness in cylinder and pan mills.

Mr. C. E. RAMSDEN:—Cylinder ground glaze seems to be always good. Recently a friend analysed two samples of the same felspar ground wet and dry respectively. The wet ground material was found to contain 3 or 4 per cent. less of alkalies. The introduction of lime in cylinders is not universal, in certain cases salt is used instead of lime.

Mr. W. F. MALKIN:—A boat load of bone was ground in a cylinder at Burslem, and was reported to be rough. It was ground again, and still reported as rough.

Much of the difference found in ground material may be put down to percentage of lime present. Richmond stones (98 per cent. SiO_2) add $2\frac{1}{2}$ per cent. silica, and Derbyshire stones (average 50 per cent. $CaCO_3$) add $4\frac{1}{2}$ per cent. lime in process of grinding. The former were tried, but the ground material could not be used. By using a mixture of two kinds (the above and another miller's) the body was found to be more fusible than when either was used alone.

Flint with 98·6 per cent. silica and less than 1 per cent. lime could not be stopped from setting. A small percentage (under 3 per cent.) of lime has a tendency to stop setting.

In the case of china stone which would not settle properly —there were 50 or 60 barrels of it in the ark—a handful of quicklime spread over it caused the surface to clear in two hours, and it settled more in one hour than it would have done in a week without the lime.

Great differences in fineness are due to cylinder mills sifting instead of washing up materials as is usual with pan mills. If cylinder ground material could be subjected to washing up it would be improved, but the output would be much smaller

XII.—The Inversions in Silica Bricks.

By Alexander Scott, M.A., D.Sc.

Introduction.

THE extensive use, in the manufacture of steel, of refractory materials consisting mainly of silica, has rendered necessary the closer investigation of the properties of this oxide. As silica bricks generally contain at least 94 per cent. SiO_2 the behaviour of the brick under conditions of high temperature depends to a great extent on the behaviour of the various forms of silica. Some of these forms had been known to exist for a considerable time,(3) but it was only after the introduction of accurate methods of pyrometry that their stability relations could be determined with any degree of exactness. The pioneers in these high temperature investigations, so far as silica is concerned, have undoubtedly been the workers in the Geophysical Laboratory, and their measurements, based on the nitrogen thermometer, are the most accurate hitherto obtained. In the earlier papers by Day and his co-workers,(1) a number of data concerning the various silica minerals are given, but the most complete investigation is due to Fenner.(2) According to the latter author, silica exists in at least seven crystalline modifications, including two forms of quartz, three of tridymite and two of cristobalite. Four of these are supposed to be stable throughout definite ranges of temperature, α-quartz[1] inverting to β-quartz at 575°, β-quartz to β_2-tridymite at 870° and β_2-tridymite to β-cristobalite at 1,470°. With regard to metastable modifications, β-cristobalite when undercooled transforms to α-cristobalite at a temperature which may vary from 240° to 198° according to the previous history of the material, β_2-tridymite when undercooled inverts to β_1-tridymite at 163°, and the last to α-tridymite at 117°. Although all these inversions are probably enantiotropic, they may be divided into two types accordingly as the velocity of inversion is high or low. The α-β transformations take place with considerable rapidity and are accompanied by a small energy change; the change from tridymite to cristobalite or quartz to tridymite proceeds very slowly and is accompanied by very considerable energy changes.

[1] Fenner's nomenclature for the various modifications is adopted in the present paper.

The importance of these points in the study of refractories is very considerable. The material from which the silica brick is made is a rock very rich in α-quartz; during the kiln burning this changes to β-quartz and partly to tridymite[11] or cristobalite; but on cooling again the β-quartz reverts to the α-form. During use in the furnace, more and more of the quartz is converted so that the brick is ultimately composed of tridymite[7] or cristobalite, as the case may be. While the brick is in the furnace, the forms which are present are the β or high temperature modifications, and the behaviour of the brick at this period depends on the properties of these. On cooling, however, these immediately invert at the appropriate temperatures to the α-forms, the properties of which are not the same as those of the former. It commonly happens that the physical properties of these α-forms, such as specific gravity, thermal expansion and so forth, are utilised in attempts to find out how a brick is going to behave under high temperature conditions. The α-β inversions take place so rapidly that it is impossible, by quenching or any other method, to preserve the β-forms down to ordinary temperatures, and any physical measurement carried out under ordinary conditions must refer to the α-forms. As there are certainly appreciable differences between the physical properties of the α- and β-forms, any attempt, based on such data, to calculate for example the possible expansion of a brick which is to be heated to 1,500°, will not agree with the results obtained in practice owing to the fact that the thermal expansion of the various modifications and the volume changes during the α-β inversions are ignored.

In the other type of inversion the transformations, while they take longer to effect, are relatively much more permanent; on cooling, the only inversions which occur in general are the α-β ones. A mass of β_2-tridymite, or β-cristobalite, will not generally revert to quartz on cooling below 870°, but will be found at ordinary temperatures to consist of α-tridymite or α-cristobalite. Hence, even if the density changes in the bond be ignored, any attempt to estimate the volume of a brick under particular high temperature conditions, will only be satisfactory if based on a knowledge of the following facts—the degree of conversion of the original quartz in the kiln-burning, and also after use under the particular conditions, the thermal expansion of the various modifications and the volume changes during the inversions. In addition, certain other factors probably come in, but these will be discussed later.

Properties of the Various Modifications.

In the present paper an attempt is made to trace the course of these inversions during the use of the silica brick. The method employed has been the microscopic examination of thin sections (5) of unused bricks and of other samples of the same batch (where possible) which have been subjected, in the crown or other parts of furnaces, to temperatures varying from 1,000° to 1,600°. Contrary to the experience of others, little difficulty has been experienced with regard to the technique of preparing the sections. Provided the "chip" received a preliminary heating in Canada balsam, to overcome the friability of the material, it is comparatively easy to prepare sections which, while not so thin as those which can be obtained from a basalt or similar igneous rock, are yet comparable in thickness with the best sections of sandstones and other sediments. The sections used had probably a thickness of the order of ·03 millimetre, which is sufficiently low for the utilisation of the optical properties in the identification of the various modifications.

The usual petrographic methods have been employed in the discrimination of the constituents. Quartz can generally be identified by the refractive index—1·544 to 1·553—which is higher than that of Canada balsam, by the double refraction—·009—giving yellow as the usual interference colour, and by the uniaxial figure obtained in basal sections. The relatively high refractive index and double refraction serve to distinguish quartz from cristobalite and tridymite. The two latter are difficult to discriminate owing to the similarity in their optical properties. According to Fenner (6) the mean refractive indices of tridymite and cristobalite are 1·471 and 1·486 respectively, and the double refraction ·004 and ·003 respectively. Mallard (11) gives somewhat higher values for the refractive indices and lower values for the double refraction. The discrimination by means of the refractive index is best made by the Becke method, minute grains of the crushed material being immersed in an oil with a refractive index of about 1·480, which is above the mean index of tridymite and lower than that of cristobalite. In employing this method it is necessary to pay strict attention to the temperature conditions, as the refractive indices of the liquids used vary considerably with the temperature, while the total difference between the indices of tridymite and cristobalite is slight. In general it is advisable to redetermine the optical constant of the liquid as soon as possible after use, and at the same temperature as during the testing of the minerals.

The double refraction affords a surer test in many instances. Tridymite is probably orthorhombic, but often appears to be pseudohexagonal and tabular perpendicular to the pseudohexagonal axis, the β-form being hexagonal. Where the crystals are tabular the double refraction is very low in the hexagonal sections, and is comparable with that of cristobalite. In all other sections, the double refraction is clearly visible between crossed nicols, although decidedly lower than that of quartz. In cristobalite, on the other hand, the double refraction is generally so low as to be invisible except with the aid of the sensitive (selenite) plate. So far as the writer's experience goes, the difference between the double refraction of tridymite and that of cristobalite is considerably greater than Fenner's figures suggest and more nearly approximate to Mallard's values, although it is difficult to understand how the latter were obtained with any accuracy.

The habits of the crystals may also be used as diagnostic criteria. Tridymite shows two definite habits, and in the course of this investigation some interesting observations have been made with regard to the occurrence of these. In one type the mineral occurs as aggregates of minute overlapping plates, with round or hexagonal outline, low double refraction, and resembling the arrangement of tiles on a roof (Fig. 8). Sometimes a whole quartz grain has been converted to such an aggregate, all the crystals having apparently the same orientation. Between crossed nicols the individuals show signs of complex twinning. The size of the crystals of this type varies, but they are generally minute. In the other type the individuals are much larger and consist of well-developed wedge or lath-shaped crystals which are usually simply twinned (Fig. 10). In the wedge forms the extinction is invariably parallel to the outer edge and not to the trace of the twinning plane. A fairly good biaxial figure is often obtained. According to Fenner, the latter are cross sections of the thin plates, but the evidence afforded by the sections examined is not in favour of this. Where the two types occur in one slide, the second type are more often found between the ganister grains, while the latter are often wholly converted to the pseudohexagonal form (Fig. 6). The latter is much smaller and no twinned edges comparable in size are found. In other sections the only constituents visible are the pseudohexagonal crystals and the glassy bond, no wedge or lath twins being seen. It is inconceivable that, throughout a section showing one-half square inch of brick, all the crystals should have the same orientation, and hence it is improbable that the two habits

are the same The occurrence of the two types will be referred to later

The habit of cristobalite is generally very different from that of tridymite. Occasionally roughly prismatic crystals occur, but these have generally multiple twinning and irregular extinction. In other cases spherulitic and other irregular intergrowths of very minute individuals are found. The most characteristic type, however, show a skeletal habit (Fig. 9). The ends of the primary and subsidiary axes are well formed, but the remainder of the crystal is simply a skeleton. These often occur in parallel growths and other aggregates, and even the simple skeletons are optically twinned.

Micro-structure of Silica Bricks.

A few investigators have given description of the microstructure of silica bricks. Most of the earlier work is summarised by Endell ([4a]), who also carried out independent work. He examined the structure and constitution of unused bricks and of similar material after use in furnaces, and in a later paper([4b]) described the modifications which appear on heating the original quartz-rock. Since the appearance of Endell's work, Seaver([15]) has used quantitative methods in connection with the proportions of the various constituents, while McDowell,([10]) in an elaborate study of the silica refractories, has also utilised microscopic methods.

Silica bricks consist of broken fragments of quartz-rock in a matrix of quartz-grains and a small proportion of bond, which generally includes a fair amount of lime. In the kiln-fired condition, ready for use, the brick is composed essentially of fragments of crystalline silica cemented together by a matrix which is mainly glass rich in calcium silicates([8]). Under the microscope, different quartz-rocks present different appearances. The chief constituent of all the types, the Sheffield ganisters, the Dinas rock of Wales and the Scottish sandstones, is quartz, the variation consisting in the amount and constitution of the cement, and the texture and structure of the rock. The statement that it is necessary to use sandstones composed almost entirely of tridymite([14]) is absurd, as tridymite is a very rare constituent of sedimentary rocks. So far as the writer is aware none of the silica rocks used in this country or in America contain any tridymite. In all the rocks employed in the manufacture of silica-refractories quartz predominates to such an extent that it is unnecessary to consider the transformations which either the cement of the original rock or the material of the bond undergoes, except in so far as the nature of these

materials affect the silica inversions. Nor is it intended to discuss further here the effect of the nature of the original rock on the refractory properties of the brick.

The examination of thin sections of an unused brick shows numerous fragments of ganister set in a matrix which varies in bricks of different manufacture. The ganister fragments, which are usually angular, are very like the original rock and have generally undergone little alteration. Practically all the grains are still quartz, and tridymite and cristobalite are absent (Fig. 1). The matrix consists of isolated mineral grains set in a groundmass, which is often glassy. The glass probably contains silicates of calcium and iron, and in some cases aluminosilicates as well. Isolated crystals of pseudo-wollastonite

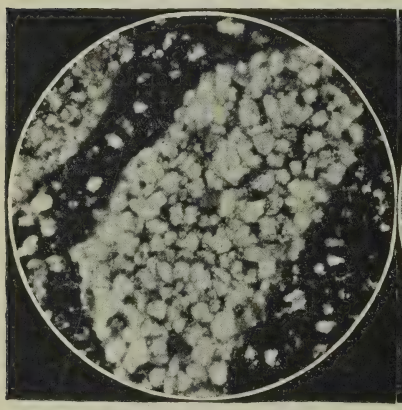


Fig. 1 — Unused brick, showing whole of one ganister fragment and part of another. Practically none of fragment is converted and many of grains of matrix are also still quartz. Dark colour of matrix is due to the presence of ferruginous material. x 30

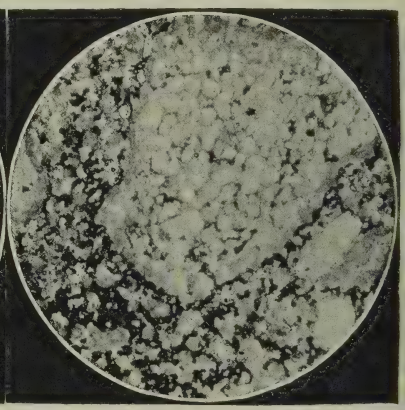


Fig. 2—Brick from cool part of furnace, showing partial conversion of fragment (round margin) to cristobalite. Matrix is entirely converted. White material is unconverted quartz and grey is mainly cristobalite. x 30

and anorthite (?) have been detected in the matrix. The smaller original grains of quartz are usually converted to cristobalite and in rare cases tridymite, while the larger grains are altered round the margins. There is usually considerable evidence of a reaction between the binding material and the small quartz grains, resulting in the formation of the silicate glass, and possibly in the partial reprecipitation of some silica as cristobalite. In some bricks, which seem to have undergone a longer firing

than others, there is a greater amount of cristobalite in the groundmass, while a small amount of this mineral appears on the margins of the ganister fragments. One unused brick, belonging to a batch which failed in practice and partly melted at a temperature below 1,600°, showed a more pronounced inversion of the siliceous material of the matrix, which consisted of a mixture of glass, cristobalite and tridymite. This conversion was probably due, not to prolonged firing, but rather to a comparative excess of basic oxides, chiefly lime, in the bond.

In none of the bricks examined, which were all British, was there anything like a complete conversion to tridymite or cristobalite, nor did the proportion of the latter minerals ever approximate to the values given by Seaver ([15]) for some

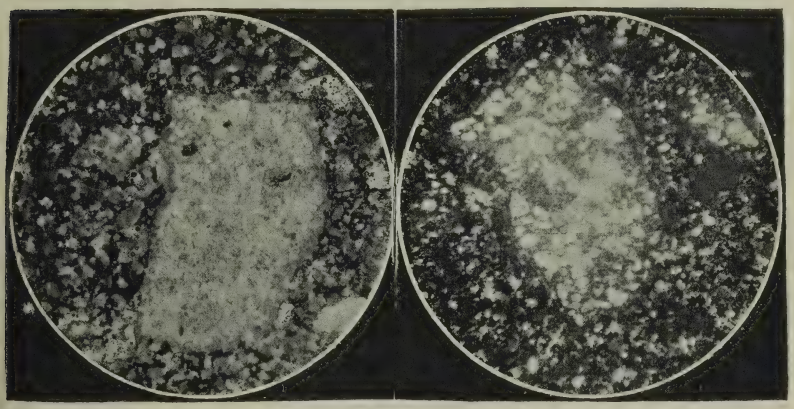


Fig. 3 — Brick showing further stage of conversion. Latter has occurred in "lanes" through brick as well as round margins. x 30

Fig 4—Same between cross nicols. The white areas alone represent unconverted quartz. x 30

American bricks. A number of similar bricks which had been used in various parts of furnaces were examined in order to determine the changes on further heating. Bricks taken from cool parts of the furnace showed considerably more conversion. The silica of the matrix is generally completely converted to cristobalite and tridymite, the proportion of the latter being considerably greater; occasional large quartz grains may have an unconverted core. The ganister fragments are also more altered, having generally a peripheral layer of cristobalite, but the quartz of the middle of the fragment still remains unchanged. The tridymite generally occurs as small simply

twinned crystals, while the cristobalite has often indefinite outlines. In cases where the bond contains some indefinite black material this shows a tendency to segregate round the quartz grains.

Stronger heat-treatment induces further conversion of the cristobalite of the matrix to tridymite, and of the residual quartz grains to cristobalite. The mode of this alteration of the ganister fragments varies with the nature of the original rock. When the latter consists of angular grains, with little or no cement (quartzite), the alteration proceeds gradually inwards from the margins of the fragment (Fig 2); but where there is any appreciable cement the alteration seems to occur whenever there is cementing material in contact with the quartz

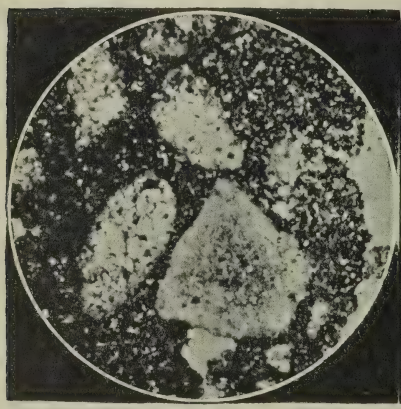


Fig. 5—Brick of same type as in Fig. 2. Showing only unconverted core in larger fragment. Others completely converted to cristobalite. x 15

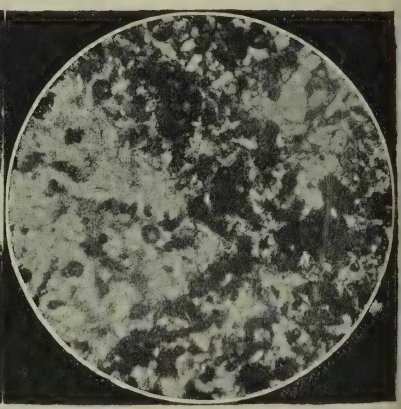


Fig. 6—Brick more or less completely transformed to tridymite, The light coloured section is a fragment of ganister converted to pseudohexagonal tridymite, while the remainder of the slide shows the other form of tridymite together with glass. x 30

grains, so that the fragment is composed of a network of tridymite or cristobalite enclosing unaltered cores of quartz (Fig. 3). The result is that while the transformation of an original quartz grain is at first peripheral, the change in an aggregate of grains may take place in different ways according to the nature of the original rock. In ordinary light the original boundaries of the fragment can generally be identified, but between crossed nicols it seems to merge into the matrix (Fig. 4).

Bricks which have undergone very strong heating, such as those from the inner hot end of the crown or roof, generally show a very high proportion of tridymite. No trace of the original quartz remains and most of the cristobalite has also disappeared. Some sections show nothing but aggregates of minute overlapping plates of tridymite, of hexagonal shape, and some interstitial glassy material (Figs. 7 and 8). The latter forms a network enclosing the tridymite aggregates, and there is no doubt that each aggregate represents an original crystal of quartz. In ordinary light it is still sometimes possible to delineate the original rock fragment, and it is noteworthy, that in some cases where twinned wedges of tridymite occurred locally, these were always found in the matrix. One specimen

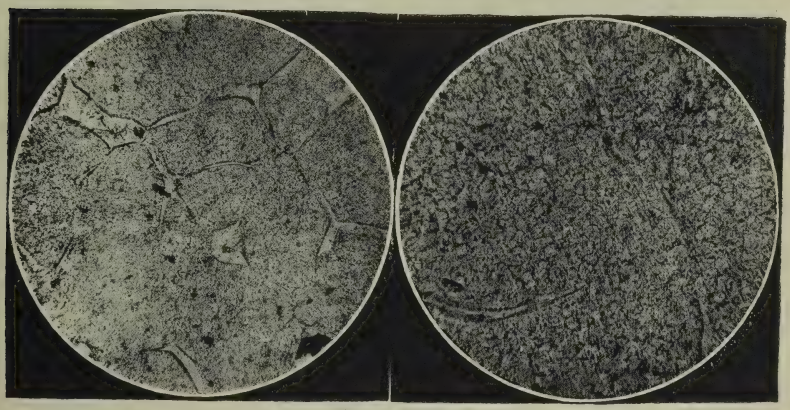


Fig. 7—Brick completely transformed to psuedohexagonal tridymite. The clear areas are made up of glass with cristobalite skeletons occasionally developed. x 45

Fig. 8—Same brick, showing overlapping plates of tridymite. x 180

showed a fair proportion of twinned laths of tridymite, but many of the original rock fragments could still be identified by the fact that they consisted entirely of the pseudohexagonal type (Fig. 6).

Cristobalite, when it is found in these "tridymite" bricks, occurs in very well-developed skeletons, often aggregated in parallel growths and generally situated in the glassy bond between the original rock fragments (Fig. 9). In some cases, late reactions seem to have taken place between the glass of the bond and the tridymite aggregates, as the latter occasionally shows a serrated edge of cristobalite skeletons

In other bricks, composed largely of tridymite, the latter belongs entirely to the simply twinned form and occasionally fairly large crystals develop (Fig. 10). One interesting point which was noted, was that while the pseudohexagonal habit never occurred in bricks which had been proved bad in practice, the simply twinned form were common in these. One brick, which had obviously melted to a great extent, had recrystallized as a mass of interlocking twinned wedges, while a few undissolved original grains had been transformed to tabular tridymite. Several bricks of different manufacture which had, with satisfactory results, been used for long periods in furnace roofs, showed only the presudohexagonal form.

Taken as a whole, the evidence not only confirms

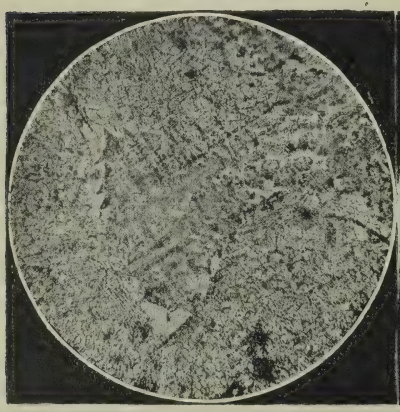


Fig. 9—Skeletal development of cristobalite in matrix between areas composed of overlapping tridymite. x 180

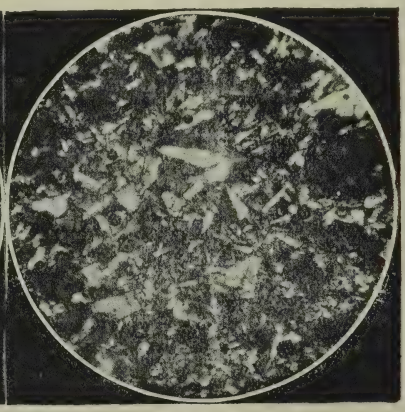


Fig. 10—Brick entirely converted to twinned tridymite. Several wedge-shaped twins are visible in centre of field. Nicols crossed. x 30

McDowell's conclusion [10] that by repeated burning (at temperatures varying from cone 13 to cone 16) the end-product is generally tridymite, but also indicates that the same end-product results when the brick has been subject for long periods to temperatures between 1,500° and 1,600° (up to cone 28). The sequence of the conversion may be summarised thus. During the kiln firing the bond reacts with some silica to form silicates which generally cool as glass, though they occasionally are partly crystalline, and the quartz grains of the matrix are partly converted to cristobalite. During use at high temperatures, the quartz of the fragments is gradually converted to cristobalite, while the cristobalite of the matrix transforms to simply

twinned tridymite. Finally the rock fragments are completely converted to tridymite, which in most cases is of the pseudo-hexagonal type. The conditions which favour the formation of the latter are not well known, but it generally devolops at the highest temperatures and in those parts of the brick which are the last to transform. This difference of occurrence opens up the question as to whether the two types are simply different habits of the same mineral or have a more intrinsic difference. It is intended to test this in the near future by a determination of the α-β, and the β_1-β_2 transition points of the two types.

Stability Relations.

So far as this work has gone, the evidence obtained does not agree with Fenner's value for the temperature of the tridymite-cristobalite inversion, but is more in favour of the idea suggested by Le Chatelier(9) that tridymite is stable above 1,470°. The former author found that tridymite inverted to cristobalite at 1,470° in the presence of a flux such as sodium tungstate, and concluded that this represented the upper limit of the stability range of tridymite. Le Chatelier, on the other hand, found that a piece of tridymite brick, heated to 1,700° for two hours, showed no sign of conversion to cristobalite. Several of the bricks examined by the writer had been subjected, for long periods, to temperatures in the region of 1,600° and yet contained no appreciable amount of cristobalite. This certainly indicates that the latter is not the stable form at the temperatures mentioned as there can be little question regarding the establishment of equilibrium owing to the prolonged heating.

The question turns to a certain extent on the interpretation of the function of the flux. The latter is often regarded as having a catalytic action and therefore hastening the inversion to the stable form, but it seems better to consider it as a true solvent in which small amounts of the silica material dissolve and from which these are finally precipitated. This view does not preclude the appearance of unstable phases, in accordance with Ostwald's rule concerning the appearance of phases of intermediate stability. Quartz may be regarded as the form stable below 870°, but above that temperature it transforms, probably firstly to unstable cristobalite, which finally inverts to tridymite. The higher the temperature, the more rapid is the inversion to cristobalite. On heating tridymite with a flux at 1,470°, cristobalite appears, according to Fenner, a fact which may be explained as follows. Above 1,470° tridymite is appreciably soluble in sodium tungstate, and some dissolves,

being ultimately reprecipitated as cristobalite. In the bricks the calcium-iron silicates of the bond act as the solvent, but, as the annealing is generally much more prolonged than in laboratory experiments, the cristobalite is reconverted to tridymite. Hence the former may be taken as an unstable intermediate phase which tends to separate out of the melt but which finally inverts to tridymite. Where cristobalite does occur in bricks heated to 1,600° for long periods, it is always found in the glassy matrix or along the margins of tridymite grains in contact with the latter. This matrix is probably appreciably fluid at 1,500°—1,600°, and exercises a solvent action of the tridymite. When the brick is finally cooled, the dissolved silica is precipitated as cristobalite out of the glassy material, but the rest remains as tridymite.

The inference from the co-occurrence of these modifications in bricks is that in contact with a melt capable of dissolving the various forms of silica, quartz is the modification stable up to 870°, tridymite is stable up to at least 1,570°, but any dissolved material is reprecipitated first as unstable cristobalite, which afterwards inverts to one or other of the stable forms according to the temperature. The probability is that tridymite is stable up to its melting point, but as none of the materials examined had been heated above 1,600° it is impossible to say this definitely. Furthermore, the melting point of tridymite is doubtful,[1] and the question as to whether cristobalite has a definite stability ranges say from 1,570° to 1,685°, its melting point, depends on whether Le Chatelier or Fenner is correct with reference to the effect of heating tridymite above 1,570°. The evidence of the examination of the silica bricks is certainly in favour of the view that cristobalite has no stable range below 1,600°, quartz and tridymite being the only stable forms. It is also very probable that the conversion of "dry" quartz to tridymite does not take place directly, but that cristobalite appears as an unstable intermediate form. A notable point is that the prolonged heat-treatment probably ensures the attainment of equilibrium. With regard to the application of this to the manufacture of bricks, one important question is concerned with the effect of bonds of different types. It may be possible that one bond will, owing to the greater solubility of quartz in it, induce the transformations to occur with greater rapidity. So long as mechanical strength is not sacrificed, the bond in which the greatest rate of inversion is found, should be used.

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1 Quinsel, *Cent. für Min.*, 1906, p. 657, gives 1,550° and Doelter, *Physikalische-chemische Mineralogie*, 1910, p. 100, 1575°. The latter value is probably more nearly correct.

Volume Changes.

The importance of these inversions, so far as actual practice is concerned, lies in the volume changes which accompany them. Numerous data by Fenner([6]), Rieke and Endell([12]) and others, for the specific gravity of the low temperature forms, are available, but there are few published figures for the thermal expansion and the specific gravities of the β-modifications. Le Chatelier has determined the coefficients of expansion of quartz, cristobalite and tridymite up to 1,000°, while Day and his colleagues([2]) have investigated the thermal expansion of quartz up to the temperature of conversion to cristobalite. The former finds that the α–β inversion for cristobalite involves a large volume change, for tridymite a small, and for quartz an intermediate volume change. It seems difficult to reconcile the large change in specific volume during the α–β inversions of cristobalite and quartz with Fenner's statement that these inversions are accompanied by small energy changes. The specific volume of α-quartz undergoes a gradual increase until 575° is reached, after which the β-modification actually diminishes in volume until it begins to invert to β-cristobalite when a large expansion occurs. Of the low temperature forms, tridymite has the lowest specific gravity, but it is probable that the β-modifications of both cristobalite and tridymite have approximately the same density.

Nevertheless, it seems to the writer that there are several good reasons for endeavouring to convert as much of the brick as possible to tridymite during the kiln-firing. The specific gravity of α-tridymite is lower than that of α-cristobalite, and hence if the β-forms have the same density, a smaller volume change occurs when a tridymite brick is raised to high temperatures than is the case with a cristobalite one. In the former case there is a small density change every time the α–β inversion temperature is passed, in the latter there is a large change which is bound to increase the tendency to spalling and also to lower the mechanical strength by the formation of cracks and so forth. If on the other hand there is a difference between the density of the β-forms, then the presence of tridymite is desirable on account of the fact that it is the ultimate form which develops during use and hence the more tridymite produced in the kiln-firing, the smaller the subsequent volume changes. Furthermore, tridymite has probably the lowest thermal expansion of the three forms. At present few bricks made in this country contain much tridymite at the end of the kiln-burning.

In actual practice, however, it is found that the volume changes are often in excess of those theoretically calculated.

According to the following values for the specific gravities of the α-forms, quartz 2·65, cristobalite 2·33, tridymite 2·27, there should be a difference in volume amounting to 13 per cent. between quartz and cristobalite, and amounting to 16 per cent. between quartz and tridymite. The writer has observed cases where the actual volume increase during the conversion of a brick during use to tridymite amounted to over 30 per cent., despite the fact that a partial conversion to cristobalite had occurred during the initial burning.

The total expansion of a brick during use in a furnace may be divided into three terms, each induced by the operation of different factors. There is firstly the ordinary thermal expansion, termed by Seaver([15]) the "temporary expansion," which is reversible and can in no way be avoided. This involves not only the ordinary thermal expansion but also the volume changes of the α–β transformations, which are reversible. Secondly, there is the so-called "permanent expansion," the volume change during the inversion of the original quartz to the ultimate tridymite. This by sufficiently prolonged firing before use could be overcome, but the question of the feasibility of this operation in mainly an economic one. There is, however, a third term which is not directly calculable from the volume changes of the constituents. This is the increase in bulk which is in excess of that calculated from the increase of the specific gravity of the finely ground material. It can generally be detected by a determination of the porosity. Ross([13]) found that on heating a silica brick to 1,400° the average volume expansion amounted to 2·8 per cent., while the diminution in specific gravity was slightly under 2 per cent., and on heating to 1,500° the corresponding averages were 9·7 and 2·8 per cent. respectively.

This increase in bulk volume is probably due to the fact that during the conversion of quartz to cristobalite and the latter to tridymite, the new-formed crystals are not so orientated as to occupy the minimum volume. The transformations are taking place either in the solid state or in solutions (in the bond) where the viscosity is probably comparable with that of solids. Fused silica, even above the melting point of cristobalite, 1,685°, has probably a very high viscosity. Diffusion will be retarded and the molecules will have slight ability to orientate themselves. This inhibition of diffusion is apparent in the skeletal development of cristobalite. The consequence is that during the readjustment which accompanies the inversion, the new form monopolises more additional space than is justifiable from a consideration of the specific gravities, and hence a greater bulk-volume, together with an increase

in porosity, results. Furthermore, it is improbable that the directions of maximum crystallization velocity will coincide in the two forms concerned in any inversion, and this variation in the directions of maximum growth constitutes another interesting factor. In connection with the two forms of tridymite, it is significant that the pseudohexagonal form was found in those bricks which showed a comparatively low expansion during use, while in those with the highest expansion the ultimate product consisted of fairly large twinned wedges and laths. In the formation of the former type the rearrangement of the molecules seems to proceed with a smaller "space consumption" than is the case with the latter type. The occurrence of this type of volume increase is an additional reason for attempting to carry the conversion as near completion as possible in the initial firing.

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XIII.—A Microscopic Study of the Bone China Body.

By Professor H. B. CRONSHAW, B.A., Ph.D.

THE following contribution is the outcome of an examination, under the microscope, of a series of thin sections cut from 21 bone-china-bodies prepared by W. H. Yates and H. Ellam[1] in connection with their careful investigations into the variations in colour brought about by effecting a variation in composition of these bodies. The sections were very kindly sent to me by Dr. Mellor.

It is feared that the present account falls a long way short of being, what one might term, exhaustive. There are difficulties in the way of obtaining very definite and satisfactory results, such as one would rarely experience in dealing with rock-sections. The general turbidity, and the extremely minute state of subdivision of the constituents, call for a great deal of patient examination, and the slides are only rendered intelligible when seen under a high power and with the aid of good light. Furthermore, the constituent minerals show many abnormal features, which is only to be expected, in view of the very special conditions to which they have been subjected.

The bone-china-bodies, which were fired at a temperature of about 1,310° C. (cone 9), were compounded of the three primary constituents, bone, china clay, and stone, in various proportions, and may be considered as falling into four series, viz. :—

1. The china clay-bone series.
2. The china clay-stone series.
3. The bone-stone series.
4. The china clay-bone-stone series.

Generally speaking, the slides are marked by showing a preponderance of an isotropic and glassy base, containing

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1 *Trans.*, **17**, 120, 1918.

swarms of crystallites and very minute gas-cavities. Through this base are scattered, in varying amounts, small angular fragments of quartz and relatively large pores; but there is an almost total absence of minerals having fully developed crystallographic forms. Compared with glassy rocks the base is peculiar in displaying a pronounced heterogeneous character, apparently due to variations in density from point to point, caused by a limited miscibility amongst the various mineral constituents of a wholly or partly fused mass of considerable viscosity. Any fluxing action, apart from simple fusion, has been strictly localised, and there is no evidence that anything like widespread diffusion has taken place. In many cases it is a simple matter to follow the original boundary of a wholly vitrified fragment of felspar, or of a wholly or partly vitrified piece of quartz. All the slides show large and small pores, which in certain cases are so abundant as to produce a sponge-like aspect. In many of the slides it has not been found possible to satisfactorily differentiate between crystallites of the globulite and cummulite types, and the extremely minute gas-inclusions, as their clear delineation lies beyond the range of the highest power brought to bear on them. The first five sections of the china clay-bone series serve to demonstrate the progressive formation of crystallites, microlites, skeleton crystals, and true crystals.

Attention may now be directed to some of the principal features exhibited by the several members of the four series.

The China Clay-Bone Series.

Slide No. 1, prepared from china clay alone, consists of a structureless isotropic base having a comparatively clear and homogeneous appearance, and contains only a few small fragments of quartz. Here and there small irregular grains, as well as prisms, of cassiterite could be detected. Crystals of zircon with good tetragonal forms, and minute slender needles of rutile are fairly common, but there were no recognisable scales of kaolin and mica, nor, as far as could be seen, any crystals of tourmaline. Gas-bubbles were not so numerous as in most of the other slides.

Slide No. 2, consisting of 80 per cent. china clay and 20 per cent. bone, contains fewer fragments of quartz, but a much greater abundance of pores. The whole presents a light brown colour, with deeper margins round the pores, and the matrix is rendered turbid by the swarms of crystallites and other inclusions.

Slide No. 289, consisting of 75 per cent. china clay and 25 per cent. bone, presents a very uniform appearance. There are fewer gas-cavities, and the matrix has a somewhat darker colour than slide No. 2. Brownish spots occur scattered through the groundmass.

Slide No 4, consisting of 60 per cent. china clay and 40 per cent. bone, is full of cavities, both large and small, and the brownish stains occur at frequent intervals. Quartz is practically absent. Examined in ordinary light the matrix is found to be crowded with ill-defined microlites and skeleton crystals. Between crossed nicols these barely react on polarised light, and owing to a variation in the amount of this reactive power when traced from point to point in a single individual, the slide as a whole presents a dark-grey dappled appearance. The microlites suffer straight extinction, which is curious, because the crystals occurring in slide No. 287 have an extinction angle of about 30°.

Slide No. 287, consisting of equal proportions of china clay and bone, is totally unlike any of the other sections, in that practically the whole of the glassy base has crystallized out to form densely compacted radial aggregates of long slender crystals. These are colourless, and occasionally show signs of an imperfect cross cleavage, and often possess well-formed terminations. The few indistinct cross-fractures which could be observed appear to run parallel to one, usually the better developed, of these terminal faces. The angle of extinction, as measured with reference to the long axis, is about 30°, although a precise determination was rendered impossible owing to the fact that only certain of the crystals reacted to any appreciable extent on polarised light. These displayed faint grey interference colours of the first order. The majority, however, were only very indifferently perceptible in polarised light. A simple microscopical examination of these interesting crystals has not yielded sufficient evidence to enable them to be identified with any rock-forming mineral. They appear to approach clinozoisite, wollastonite, or disthene most closely, although the temperature to which they have been subjected and their probably complex composition would appear to rule out of consideration the third. Moreover, clinozoisite has an extinction angle of —3°, and wollastonite has a higher birefringence and probably a more simple composition than the mineral under consideration. One is inclined therefore to suspend judgment until some of the material has been isolated and a chemical analysis made. Probably it is

a calcium aluminium silicate of somewhat complex composition, in view of the fact that practically the whole of the material has crystallised out. The brownish spots, which were mentioned as occurring in some of the previous slides, were found here to have developed into globules of glass filled with minute indeterminable mineral inclusions.

Slide No. 7 consists of 40 per cent. china clay and 60 per cent. bone. The slides cut from material containing over 50 per cent. of china clay present much the same general features. Those, however, with less than this amount, similarly exhibited distinct relationships to the section cut from bone only. Thus slide No. 7 presents a uniform and very finely granular appearance. Pores are fairly frequent, quartz is rare, and brown patches are absent. Between crossed nicols the section has a dark-grey and indistinctly speckled appearance due to the weak double refraction of the granules, or, what is probably more correct, of parts of these granules.

Slide No. 288, consisting of 25 per cent. china clay and 75 per cent. bone, is more uniformly and finely granular than slide No. 7. The colour is also somewhat darker, and the bubbles are larger and more plentiful. No quartz was observed.

Slide No. 11 contains 20 per cent. china clay and 80 per cent. bone. Here the pores become extremely abundant, more so than in any member of the series, but are smaller and of a more uniform size than is usually the case. The colour is much the same as that of slide No. 288. There is an extraordinary abundance of quartz fragments, and here and there occur small patches of brownish glass free from granules.

Slide No. 16, consisting wholly of bone, is apparently a closely compacted aggregate of extremely minute and irregularly shaped isotropic grains, showing a remarkable uniformity of size. At certain points traces of a glassy matrix can be discovered. Pores are not very common.

China Clay-Stone Series.

Slide No. 3 consists of 80 per cent. china clay and 20 per cent. stone. This section possesses the same general characteristics as slide No. 1, although quartz is more abundant. A few crystals of zircon and cassiterite were seen. Pores are practically absent. A curious feature is the presence of swarms of irregular granules having a very high refractive index, which are more or less confined to certain areas and winding bands.

Slide No. 6, with 60 per cent. china clay and 40 per cent. stone, shows a considerable number of quartz fragments set in a turbid isotropic groundmass. Here and there are small patches of clear brownish glass. Many of the quartz fragments illustrate various stages of solution. In some cases they have melted as a whole to give clear glassy interiors and sharp outlines. In other cases a process of solution has advanced either regularly or irregularly from without. The highly refractory grains mentioned in connection with slide No. 3 occur within this section in even greater abundance. Pores are not numerous.

Slide No. 10, with 40 per cent. china clay and 60 per cent. stone, has the same general appearance as slide No. 6, showing about the same number of pores and highly refractory grains. Quartz, however, is rather more plentiful.

Slide No. 15 consists of 20 per cent. china clay and 80 per cent. stone. Here the pores become large and extremely abundant, otherwise the section is similar to No. 10.

Slide No. 71, consisting entirely of stone, possesses a glassy groundmass crowded with minute fragments of quartz, of which the larger show distinct outlines in both ordinary and polarised light. Here and there are brownish turbid patches which seem to represent vitrified crystals of felspar. Rounded cavities are numerous, some being partly or entirely occupied by a completely isotropic glassy material, rendered turbid by dense aggregates of very small dark inclusions. Examined between crossed nicols the groundmass presents a dark-grey mottled appearance due to the presence of the smaller fragments of quartz, which react in various degrees on polarised light, and this also applies to different parts of a single individual.

The Bone-Stone Series.

Slide No. 17 contains 80 per cent. bone and 20 per cent. stone. Although in a general way similar to slide No. 16, the groundmass is somewhat more coarsely, yet indistinctly granular, and contains a greater abundance of cavities. Quartz fragments are likewise present.

Slide No. 18 contains 60 per cent. bone and 40 per cent. stone. In this both cavities and fragments of quartz are larger and more numerous than in slide No. 17. The former have an unusually irregular shape, and the granular texture has disappeared

Slide No. 19, consisting of 40 per cent. bone and 60 per cent. stone, resembles slide No. 18 in appearance, and is studded with bubbles to about the same extent. There is, however, more quartz, and there are fine, indistinctly outlined needles arranged with their long axes parallel to one another. These needles have no action on polarised light.

Slide No. 20 consists of 20 per cent. bone and 80 per cent stone. This section only differs from slide No. 19 in possessing more quartz.

China Clay-Bone-Stone-Series.

Slide No. 5 contains 60 per cent. china clay, 20 per cent. bone, and 20 per cent. stone. It has a uniform texture and light brown colour free from darker patches. Fragments of quartz and pores are few in number. Most of the groundmass is turbid from inclusions, although there are occasional patches of clear brownish glass.

Slide No. 8 contains 40 per cent. china clay, 40 per cent. bone, and 20 per cent. stone. This section is very similar in appearance to slide No. 5, possessing the same uniform texture and colour.

Slide No. 9, consisting of 40 per cent. china clay, 20 per cent. bone, and 40 per cent. stone, differs from slides Nos. 5 and 8 in having a still more turbid groundmass, a little more quartz, and larger pores.

Slide No. 12 contains 20 per cent. china clay, 60 per cent. bone, and 20 per cent. stone. The main part of the section is essentially similar to slide No. 8, but at certain points patches of material with much the same appearance as slide No. 288 are seen.

Slide No. 13, with 20 per cent. china clay, 40 per cent. bone, and 40 per cent. stone, possesses a more uniform texture than slide No. 12, and is also somewhat more turbid. Quartz is fairly abundant, but pores are practically absent.

Slide No. 14 contains 20 per cent. china clay, 20 per cent. bone, and 60 per cent. stone. Here the small angular fragments of quartz become very numerous, and, generally speaking, the section is full of small rounded cavities, although there occur areas in which the cavities are fewer and smaller. Small patches of clear brownish glass are quite frequent.

XIV.—The Encouragement of Art in the Potteries.

By A. E. Gray.

I DO not think any apology is necessary in bringing before this Society the question of art in the Potteries, either in a general sense, or art as applied to pottery; but at the same time I wish to apologise to the members of the Society for presuming to be the present medium of that discussion, because I feel my inability to deal with the subject in any sense exhaustively. My excuse is that we ought as a community to meet the occasionally hostile criticism offered from outside, and if such criticism is found in any measure based on facts, ought we not to see if it is possible to remedy our faults?

The Potteries from time to time have been severely criticised on the lack of beauty in the district, and general conditions of labour.

A number of these criticisms have obviously sprung from a very superficial knowledge of the district and the people, and have in consequence received but scant attention, but other criticisms are such as we cannot afford to ignore.

It may be possible for us to become so accustomed to the conditions under which we live as to love even the ugliness of our towns, sentiment has such a powerful influence upon our outlook; but I fear that even residents cannot blind themselves to the fact that the Potteries are far from beautiful.

One is struck on entering the Potteries for the first time with the general lack of beauty. It is true that few industrial centres are beauty spots, but the ugliness of the railway bridges, the meagreness of the buildings, public and private, and the want of order and narrowness of our streets strikes most visitors; most of the factories seem to have slipped away into back streets, out of very shame for their ugliness, and yet a pottery in itself need not by any means be ugly. The dome chimney of a potter's oven is infinitely more beautiful than an ordinary factory chimney, but so many of the works in extending have added a few cottages here, or built another shop there, crowding each other without any consideration for

the architectural result, and often without sufficient consideration for efficiency in manufacture.

We have some modern factories, which have at least the merit of being built on the best principles for saving labour, and will compare favourably with any trade in suitability for the purposes intended, but very few factories could claim any special beauty in their structure; 'tis true that a quaintness that age has kindly given makes some of the older factories of more than passing interest, but our district lacks that nobleness of building which is the outcome of a strong vigorous industry, imbued with pride of locality and public spirit.

We have seven town halls (one township possessing two), five museums, small and so separated as to give the utmost possible trouble to the curator who has control, and to any designer or potter who is enterprising enough to consult them. This is the more unfortunate because much trouble has been taken and expense incurred to collect sufficient valuable pottery to make one first class museum. We do not possess an art gallery.

Few of our public buildings are of sufficient importance from an architectural point of view to attract attention, and a general tone of sombreness and squalor prevails, that is surely not essential to the manufacture of pottery.

It is necessary to consider the question of general art before dealing with art as applied to pottery, because I think we cannot expect a high tone of taste, in our production, unless an appreciation of the beautiful exists in the community, and one can only suppose that is lacking when one sees so little beauty expressed in our town life.

There is little that is beautiful in the manufacture of iron, cotton and some others of the staple industries of this country, but the same cannot be said of pottery, which is essentially an artistic product, the finest specimen of pottery depends, not on the value of the raw material—a few pence might cover that—but on the amount of skilled craftsmanship displayed in its manufacture.

I believe we have to-day as fine craftsmen employed in pottery as ever, and would go further, in saying that we could excel all the past work, in that we have the wonderful traditions that exist not only as an incentive, but as an hereditary influence; that force needs the opportunity of expression, and encouragement to develop.

The TRANSACTIONS of this Society point to the extremely exhaustive character of the research work done on the scientific side of pottery manufacture, but one finds very little indeed that has been done by the Society in the interest of the

artistic or decorative side. Science and art must work side by side if English pottery is to take its proper place in the world's markets, but I fear it is impossible to escape the conclusion that as far as this Society is concerned the artistic side has been neglected in the past.

I take it that the Ceramic Society, by its name, is interested in all phases of ceramic art, and also in the commercial aspect.

It is, I feel sure, the artistic side that the buying public is most interested in. Comparatively few are able to judge the merits of body or glaze, and it is open to question whether the mechanically perfect piece is not too metallic in its perfection, and has not lost some of the plastic qualities of pottery. I am inclined to think that good decoration on more or less indifferent ware is more acceptable to the buying public than technically perfect ware of less attractive decoration.

I think it would be well to elicit the interest of designers, and those engaged on the decorative side of pottery, in the work of this Society; the decorative side of pottery employs a very large number of operatives, and is an extremely important side of the ceramic industry. It is outside the scope of the discussion this evening to deal with the technical side of art, but it would prove of exceeding interest if lectures could be arranged in connection with this Society dealing with the purely decorative side of pottery, historical and practical. I believe it would be quite possible to arrange for Mr. Rackham of the South Kensington Museum, one of our best authorities on historical pottery, to give a lecture on this subject, from conversations I had with him recently.

We have a number of extremely capable local designers, who would surely give their assistance in the direction of improved design, and it should be possible to find decorative managers and designers who would deal with the technical difficulties of decoration in the same way that this Society has dealt with the scientific side of ceramics.

Of the artistic merit of modern pottery one can say with confidence that there is room for much improvement. particularly in the cheaper goods, and that is the class of goods I think we ought to direct our particular attention to. We seem to have moved in a vicious circle in that grade of pottery, copying one another, undercutting prices and cutting down wages, with most serious results so far as design is concerned.

Those who can afford to purchase expensive pottery are well catered for, and they have little excuse if their selection is inartistic, though even in that grade of pottery the demand

for novelty has led very frequently to the production of goods of bad taste.

Perhaps this period has been more imitative than original in the developments of commercial design, and it is regrettable that we shall have little to show that is distinctly original in decorative scheme. It is possible to use the best of traditions to cramp original thought, and one is inclined to think that some firms are suffering considerably in this direction. Fortunately there is a public that is prepared to buy goods on their face value in design, irrespective of the name on the back, and any attempt to live on reputation must suffer.

Greater originality in decoration is shown by manufacturers of fabrics and wallpapers than in pottery, as I think will be admitted by all, and most of us are conscious of the inspiration received from tapestries, etc., in designs and colour schemes for pottery. Of course one must admit at once that the range of dyes is very much greater than that of ceramic colours, but the danger is that we may be inclined to accept our limitations too readily, and are perhaps more inclined to rely on the safe thing than to attempt a really bold use of colour in decoration. Colour is of course emotional, and probably reflects more than anything else the surroundings of the producer, hence the bright colours of Eastern pottery. Fortunately we have got away from the drabness of the Victorian period, but with more beautiful surroundings we ought to see that beauty expressed in our productions.

The manufacture of pottery, or any other product, carries with it the responsibility not only to produce goods of commercial value, but also that of producing them of the best taste. There is a great educational factor in the use of good design in pottery in the home, as one of the first impressions of applied art to the child comes through the articles of daily use on the table, and if those articles are ugly in shape and design, the child's mind is warped towards ugliness, but on the other hand, the use of the beautiful must affect, imperceptibly perhaps, but none the less surely, the development of the love of beauty in the child; and from that the character and life. This is a point not freely accepted by manufacturers, the general remark made by those producing obviously ugly goods, and admitted by them to be such, being that they only produce what the public demand, and that they cannot afford to educate the public, but surely this is bad logic. We cannot afford not to educate the public if we look at it only from a commercial point of view. The present time is our great opportunity in English pottery, now that the production of Austrian and German pottery is not only out of our own

market, but also all markets throughout the world; it ought to be possible to set up in those markets a taste for English goods. Undoubtedly fashion is a factor in pottery, as in fabrics, and if that fashion for English goods were established in countries hitherto using Austrian and German goods, the market would be retained with greater ease after the war. Of course it is no use submitting to these markets goods in English taste, or the outcome of English tradition, but we ought to have the artistic ability to supply them with goods in their own fashion, but carried out in a thoroughly artistic manner. To enable our artists to do this, however, we might make more use of the Board of Trade Intelligence Branch. Japan has seized that opportunity, and is producing not only the purely ornamental but useful articles, and will prove a strong competitor in certain markets in the future. She has thrown over a good deal of the traditional eastern decorations, and is producing goods more suited to the taste of the respective markets.

Mr. Eyre, in his lecture before this Society during last session, pointed out the merits of the Austrian and German pottery shown by the Board of Trade at their exhibition in 1915; he was perhaps more eulogistic than we could accept in his praise of their products compared with ours, but there are undoubted merits, particularly in Austrian goods, which in the cheaper articles seem generally of better form and design than our own cheap pottery. The advantage of felspathic body may be responsible for a good deal; we are perhaps compelled by the faults of cheaper earthenware to elaborate ornamental embossments, and over decorate, to cover faults of glaze.

One interesting point in Mr. Eyre's lecture was the mention of the German *Werkbund*, and its influence on commercial design. The Austrians, I understand, have an institution, or institutions, for the encouragement of art among their operative classes. These institutions, I understand, have been the means of developing a more definite artistic feeling among the craftsmen, and I think we must agree that a man who understands the practical side of his trade is much better able to produce commercial design than those whose training is more or less theoretical only.

The first essential in designing an article is utility. A jug or teapot should pour well, and be easily cleaned. Simplicity of outline, and plainness of surface, is necessary to carry out those requirements, and yet how many of the shapes one sees, particularly in cheaper jugs, are spoiled by needless ornaments, and extravagance of shape.

The constant demand of the buyer for something new has led no doubt to the production of mere novelty, apart from beauty of design, or fitness for the purposes intended.

In addition to the need for educating the producer of the goods in the knowledge of art, and the love of beautiful, it is also necessary to give the buyer and seller that opportunity.

Messrs. Selfridge have already realized the importance of this point, and are giving their buyers facilities for special training in applied art. It would be of great value to this district also, if our representatives had similar opportunities, because one knows that a man can always sell that pattern he partcularly likes, and training would make it possible for him to appreciate more fully, and point out the merits of good design.

Much is possible in the direction of co-operative effort in education by the recently formed National Pottery Council. The art side of pottery should be treated co-operatively as well as the scientific. Dr. Addison, in his remarks at the formation of this Council, stated that "No industry can prosper that keeps its customers poor," and we cannot afford to keep our customers poor in quality of our goods in either a technical or artistic sense.

The Designs and Industries Association have been particularly critical of modern pottery, and have perhaps angered a number of manufacturers by the exhibition, last year, of the more or less crude pottery, and its advocacy of hand-work in decoration, without due regard to the question of output.

I am not particularly concerned this evening in the question of supplying artistic pottery to an exclusive public that can afford to pay for the limited amount of hand-decorated pottery that could be produced, though one is, of course, extremely interested in that development, but I think that it is more important we should take more interest in the production of the bulk, with all the advantage of machinery and process work, being in the best possible taste.

The last ten or twelve years has seen great improvements in pottery decoration. Lithographic transfers have done much to brighten the cheaper productions, and used with due regard to their suitability to the article to be decorated, have proved of great value; but the popularity of the litho has led to much that is in bad taste, by the use of designs altogether unfitted to the piece being decorated. A litho may be quite happy as a border round a plate, or cup and saucer, but the same border if used as vertical stripes on a jug or flower pot might be in very bad taste.

Lithos generally are too indiscriminately used, the easiness of the process has often led to their use without due regard to the intention of the lithographic designer.

The combination of litho and blown colour seems particularly dangerous to good design.

We all know that a serious attempt has lately been made to put the local schools of art on a thoroughly business-like and artistic footing, having a direct bearing on the staple industry; these reforms seem to be suggested and carried out in a most practical manner, and are being applied under an enthusiastic and able Art Director, Mr. Stanley Thorogood; one hears from practical men in the trade that the effect of the training upon the operative has already proved most beneficial. But there is very little interest taken by the manufacturers in art school work, nor are the operatives very enthusiastic; probably that is a question of wages. I am afraid we must all agree that wages in the pottery industry are low, and that generally the operatives have very little to encourage them to improve their quality of work by training at art schools.

It is a matter of surprise and great regret that the highly trained art students of this district aim at getting out of it as early as possible, finding little to encourage them to stay; this is also a question of wages.

Parents are reluctant to put their children to the trade owing to the poor wages paid; boys are paid so much better for working down a pit than in a factory, even for skilled labour.

Can the trade afford to allow this leakage of the quality? Art in production should be treated as an investment, not as a luxury; the results may not be apparent immediately, but we must not allow English pottery, even of the cheapest grade, to become eclipsed by goods made by a friendly or unfriendly nation.

The amount of trouble and expense taken by the Germans and Austrians to gain the overseas trade is apparent in the elaborate catalogues, a few examples of which can be seen here this evening; these catalogues show a carefulness of detail that commands business. Some are printed in five languages.

I do not by any means bring these catalogues, which the Board of Trade Intelligence Department has kindly placed at my disposal, to show artistic merit. Some undoubtedly are good, most are very poor, but they quite clearly show the enterprise on the part of manufacturers to capture trade.

A local manufacturer of litho catalogues estimated that one of these catalogues would cost at least £5,000 to produce an edition of 5,000, and this to illustrate cheaper glass.

I do not think that the capture of markets is only a matter of price, though even there the specialization and concentration on a few lines shown by the Austrian and German factories might be considered with some advantage by ourselves, but the most important point in the long run is the improvement on the artistic side.

One of the things that the National Council should pay attention to is the safeguarding of originality in design, and a better understanding between manufacturers on the question of copying; unfortunately the one that copies generally spoils the original, and only does it with the object of cutting price.

That is a matter of finance, for I am afraid that any enterprise on the part of individual manufacturers towards more artistic productions must entail an outlay of capital that will not see its proper return for some time, and, though more satisfaction is derived from the production of good artistic pottery, money is made more quickly by the maker of the cheap and nasty. It must be admitted that there is not a proper return for the amount of skill shown, and risk run in the manufacture of pottery, and that prevents very largely the fuller expansion of the industry.

What are the means that could be adopted to encourage art in the Potteries, so as to improve our production? I don't think we can expect any great improvement without raising the tone of general art in the district, and would advocate the establishment of a central art gallery, or at least an attempt to form a permanent collection of pictures. This may sound very ambitious, but the occasional purchase of a painting, and the probability of gifts, would no doubt soon establish a collection that would prove a splendid nucleus for an art gallery later on.

Manchester during the last year received gifts for their art gallery of the value of £150,000, and surely we ought to expect something to be done in this district if we laid ourselves out to obtain assistance and provided a suitable place to house them.

An annual exhibition of pictures on loan could no doubt also be arranged, as well as lectures on art, as in other towns. Manchester has an excellent system of giving elementary training to children on art, by arranging visits of school children to their art gallery, where they are given lessons on the pictures by their teachers, who have been previously coached by the curator, the children afterwards writing essays, with most satisfactory results.

There is great need to establish a central museum, large enough to properly display the specimens of pottery we

possess. The present museums are too small and cramped, and altogether too scattered. The nucleus of a fine museum could undoubtedly be got out of the present collection, if brought together and arranged as we know Mr. Caddie could arrange it. This museum should be directly connected with the school of art, with easy access for students, and should include a good historical record of the craftsmanship of the district.

Of course each town naturally wishes to keep its own museum, that it has itself taken an interest in establishing; but it is an undoubted fact that many beautiful pieces of pottery in this district have not the educational influence that it is possible for them to have, because pottery designers have not the time to run about to half a dozen places to see isolated specimens that would be much more telling if all seen in one splendid collection.

As practical business men we ought to insist most strongly on this particular point. We should not allow any local jealousies to prevent the establishment of a great central museum, worthy of the district, which would prove a great asset in the development of our industry, and would be of considerable interest to visitors. The present loan collection from South Kensington, on show at Hanley, illustrates the support that the Board of Education are prepared to give to any enterprise on our part.

No clear-sighted business concern would ever dream of running five little factories instead of one fully efficient big one, and if our municipal authorities are going to take advantage of approaching opportunities they cannot afford to be any less efficient than a good business concern.

The main idea of a museum in the Potteries should be the collecting together of pottery, not only to form a historical record, but also such specimens as would prove of educational value to the student and an inspiration to designers, in either decoration or shape, an entirely different point of view to that of an ordinary collector, who apparently aims at obtaining rare pieces without due regard to beauty.

A most important movement would be the collection of specimens of contemporary pottery, both English and foreign.

The foreign pottery would show us as a manufacturing community what we are up against, would bring our historical side up-to-date, and also prove a great source of inspiration.

The English contemporary pottery would complete the historical record, and would prove of some encouragement to manufacturers to improve design and merit their inclusion in a collection of this kind. Take pottery painting alone, what-

ever may be the opinion of its artistic value, it has of late years been carried to a point of excellence undreamt of by anyone who has not seen the best specimens that have been produced by Messrs. Doulton, at Burslem, during the last ten or fifteen years, and anyone who has seen the beautiful hand decoration produced by Messrs. Wedgwood, of Etruria, on dinner ware, must feel the keenest regret that specimens of this lovely work cannot be seen by members of the very community in the midst of which it is produced.

In addition it ought to be possible, at comparatively trivial cost, to found a branch of the museum, which would be simply priceless in its influence on the future craftsmen of this district. I have no doubt we all agree that the manufacture and decoration of pottery has probably produced a body of craftsmen, whose excellence craftsmen in any other manufacture could scarcely equal; the old-established firms in this district must have thousands of original designs, drawings, and engravings, lying in their folios, which if carefully selected, and exhibited in chronological or any other order that is advisable, would form a marvellous exhibition of the skill and ability of the men that have lived and worked in this district.

Think of the working drawings of men like Solon, Mussill, Reuter, Lessore, Alfred Stevens, Flaxman, Cutts, Allen, Boullemier, Fred. Hancock, Raby, and hosts of others less noted, but in their own particular field not less able. These drawings, etc., are in existence, and surely the firms who possess them would be only too glad to allow some of them to become part of a collection intended for the benefit of the district, and not only for the benefit of the district, but think how our credit would be increased in the eyes of numbers of visitors, who will certainly be coming to see us in the expansive days after the war.

Of course it seems hopeless to expect that work like this would be successfully carried through by a municipal authority whose ideas of the importance of this side of the local industry must be gauged by the fact that they only allow £1,500 a year for the maintenance and extension of the five museums.

But may we hope for a greater interest to be taken in the existing agencies for the improvement of art in our town life, as well as in our productions, by the manufacturers and operatives, if only in self-defence, and a public spirit created which will be above petty jealousies, and capable of taking a broad outlook on the needs of the community in the present and the great expansion possible in the future, that our district may not be despised for its unloveliness nor our industry for its poverty.

DISCUSSION.

Mr. F. JONES:—An important question arises in connection with the encouragement of art as applied to pottery. Is it to be commercial interest or ideal? I am reminded of Sir Henry Cunynghame's presidential address on "Art and Common Sense."

It is most difficult to educate all the buyers. The large sums spent on artistic decoration at establishments like Cauldon Place Works, Wedgwoods, and Doultons have not been repaid by trade.

The teaching in art schools in this country has been most detrimental to art productions. The courses have killed all originality and individuality.

The large local firms have employed some of the finest artists and designers in the world. Cutts's designs would cost as much as £300 to £400 to engrave American services, and manufacturers cannot afford to produce them.

At the Chicago International Exhibition art productions of Germany were returned, while pieces from Worcester, Cauldon Place, etc., sold well. After producing these beautiful sets the best workmen had very little to do.

Most of the pottery works have by irregular additions and alterations grown into ugly places, and now the cost of altering them would be too great.

Mr. STANLEY THOROGOOD:—Undoubtedly far more interest was taken in the schools of art years ago than is the case to-day.

A difficult problem lies in the fact that parents are diffident about putting their young children to the industry, and the aim of the most highly trained craftsman is to get away from the district.

It is a pleasure to know that the few manufacturers and art directors who visit our schools very much appreciate what is being done in the direction of assisting the industry.

It is very necessary that our art students should receive a broad art education, as the division of labour on the factory only tends to make them victims of their machines.

I was pleased to note the reference to the necessity of an art gallery in this district. The possession of an art gallery would enable us to have loans of important works of art from time to time, both English and Continental.

The idea of collecting contemporary specimens of pottery and other crafts for the benefit of industry and commerce is already in operation on the Continent, and such specimens are exhibited from time to time in various industrial towns.

Mr. A. G. RICHARDSON:—Artists have had a good chance in the Potteries, but purchasers have been very few for some time. I would like our country to secure the first place in the market from an artistic standpoint as well as scientific. But we cannot enter into international competition except on a profitable basis.

The thought has occurred to me that artists might perhaps be used more if they could be employed more in departmental work instead of purely artistic work. They should still be able to exercise an effective influence on the art side. The question of market is a practical difficulty.

Mr. T. H. SANDLAND:—*All* art is not necessarily good. Opinions differ very much as to what is good art. If factories in the Potteries are to cultivate certain markets they must make articles which are certainly not artistic.

It is no use going to the East End of London or certain colliery districts with good artistic shapes and decorations, they call for "rococo," and the manufacturer who does not give it them does not get the trade.

No firm can run a factory exclusively on high class art goods; very often a manufacturer makes his money out of the cheaper grade of goods, and runs some high class goods purely as an advertisement.

Art is the twin brother to profits in the Potteries, and profits is the more favoured of the twins.

Mr. Gray called attention to the fact that some border patterns were eminently suitable for plates and similar pieces, but to put them indiscriminately on all other kinds of ware, jugs, etc., is bad. I admit it is bad, and plead guilty to inflicting some such on the public—*but they sell*.

Mr. A. J. VAUGHAN:—In many cases a manufacturer will employ a designer, but he himself selects the samples for submission to the customers. This, in my opinion, does not give the designer's work a fair chance to be brought properly before the buyers.

Mr. A. LEESE:—Mr. Gray's paper is thoroughly practical. In my opinion the new National Pottery Council is going to do wonderful things. Most of us are descended from potters and artists, and have talents which cannot be utilised for want of appreciation and encouragement by the manufacturers in general.

The trouble with the lost talents of the Potteries is want of appreciation and the wages question. I hope that something fuller will follow now for the artistic side. If art and

science were brought closer together, and more encouragement given to their employment in manufacture, there is no doubt the trade in general would be in a higher state of perfection than it is to-day.

Mr. F. R. WILLIAMS:—Taken as a whole, the public in general needs educating to appreciate art and artistic productions; in many cases good artists cannot exist because their work cannot be sold. Manufacturers are obliged to produce goods that are in demand, thus if the public is educated to appreciate and demand artistic goods the manufacturer would be able to employ good artists and produce artistic ware.
repairs.

Mr. C. P. SHAH:—This country does a great bulk of oversea trade in exporting pottery to different countries. These countries have, as a rule, a special liking to their own designs and colours suitable to their climatic conditions. If the manufacturers study the art and utilise these designs in decorating different kinds of pottery, I believe they can do better trade.

Printed cotton goods manufacturers of Lancashire have tried to study the art designs suitable to the requirements of the users, and this is one of the reasons why they export 80 per cent. of their output to India.

Most of the manufacturers are rather too slow in adapting themselves to the artistic requirements of their buyers, and hence the Germans have superseded them in capturing trade in foreign markets. I know in one or two cases they were able to replace English goods completely with their own by simply meeting the artistic requirements of the customers in printing trade. No doubt it required initial outlay, but it paid in the long run.

Mr. A. E. GRAY:—The important point is the necessity to raise the tone of the cheaper products. While we have to supply the East End of London, Indian and other markets, with goods suited to their requirements, we should aim at treating such designs and colour in a more artistic manner. We ought to be able to supply cheaper grades of pottery as artistically as cheap fabrics, and ought to try to create fashion instead of copying other products.

Little appreciation of good design is shown commercially, many buyers being more interested in low prices than in the artistic merit of the goods. A business shorn of ideals is decadent, some firms have tried to live on tradition and have lost ground in consequence.

COMMUNICATED DISCUSSION.

Dr. J. W. MELLOR (communicated Jan. 19th, 1918):—In dealing with any particular subject, I always try to get hold of some sound guiding principle, I have failed many a time in politics when the elections have been on, and have accordingly refused to vote. For the last dozen years I have also been groping for some guiding principle in art, and so far my groping has been in vain. I must confess that we appear to be up against a stiff proposition when the attempt is made to find just what is meant by an artistic or a beautiful production. When we ask for more art, less art, or better art, the request can scarcely be satisfied unless we are clear what is meant by the term. We are told it is fundamentally something which is in good taste. Whose taste? Are there not fashions in art? Fashions in good taste? We have heard speakers deplore the barbarity of the art required for the East London market, and protest against pandering to the bad taste there in vogue. Perhaps it is, but I do not know, I never did know what an artistic production means. We have heard speakers pleading for a study of the customs of particular countries so as to be able to make goods to satisfy the prevailing taste, and accordingly capture the trade of that country. That seems common-sense talk. I was told in Lancashire that an art calico printed with hundreds of hands each pierced by a dagger from which a stream of gore seemed to be running, proved exceedingly popular in the West African market. This pattern seems to have been highly artistic to the West African, and therefore, dare we say, in good taste. I have seen what is considered to be in good taste by the Singalese, the Australian aboriginal, the Arabian, the Maori, etc. I know that certain artistic figures on some of our artistic pottery would be blasphemy among, say, the Buddhists. I therefore inquire who is to judge what is good or bad taste? Now I ask is the East Londoner's taste, which has been condemned, really bad, or is it merely that some of us think it bad. I should like a vote in East London taken on the merits of some of the alleged atrocious designs. Not very long ago a hand-decorated French vase was placed on the table before a few of our leading designers or art directors, and about half voted the decoration artistic and beautiful, and the other half voted it barbaric and ugly. Does not this mean that my own doxy is orthodoxy, and the other man's doxy is heterodoxy? I raise these points before our guests, whom we are very glad to have with us this evening, merely as one who wishes to learn from them. I remember one evening sitting beside a dear

old lady watching the sun set across the Indian Ocean. The colour effects charmed us both, but she gave me a brutal slap by saying that the crimson streaks in the grey purpled clouds reminded her of the streaks of lean in a slice of good fat bacon. If the war keeps on much longer perhaps a lot will agree with the lady that a slice of good fat bacon is a beautiful thing, and one with the best of tastes. The late Mr. Solon used to say that I was a hopeless case, past all redemption, and therefore as a complete outsider in art, I ask the professors of the art of beautiful designing, if after all has been said, a beautiful thing is not something which pleases me personally, and an ugly thing, that which I dislike, no matter who says the former is ugly and the latter beautiful. Beauty, said the poet, is in the eye of the beholder. Does not this sum up the position? If what the Staffordshire artist calls beautiful, the East Londoner calls ugly; and if what he calls ugly the East Londoner calls beautiful, so much the worse for the Staffordshire artist if he refuses to do what he is advised to with the West African market, and try and appreciate the beauty in what he imagines to be an ugly thing. Mind you, I am speaking as one who knows nothing about the subject, but on that account my confidence in what I say is all the greater. At any rate I have succeeded in muddling myself, but I take it these questions had far better be discussed in a society of art designers and artists than by a technical society like ours. I therefore suggest that our guests form a society of their own for the discussion of their own problems. It should be possible to run a totally independent society, say an independent Art Section of the Ceramic Society with its own President, etc. I have a dim notion that our Society has been of material benefit to the technics of the clay industries, and I have some confidence in predicting that an analogous Society among the designers and artists is wanted; I trust that if such an Association be formed it will have a rich and abundant harvest.

SIR HENRY CUNYNGHAME (communicated Jan. 31st, 1918):—So many theories have been proposed as to the nature of art that it is necessary to apologise for adding to their number

My long association with Stoke-upon-Trent, however, seems imperatively to demand that I should try and express those views respecting the art of the potter which I have long and steadily held.

In the first place, then, I may observe that the word "art" stands for any group of rules or principles arranged with a

practical aim. Then we have arts of war, of navigation, of government, of architecture, and so on. Some of these arts aim at the correct management of ships, of building of houses, others at arranging good laws. But the arts with which we are concerned are the æsthetic arts, that is to say, the arts whose object is to awaken or increase human emotion. Emotions may be of different kinds. The lower ones are the pleasures of the palate, the pleasures of the dance, the emotion of joy in fighting or of overcoming resistance. The higher those accompanying poetry, music, painting, and the study of science. These emotions may be either pleasurable or painful. When pleasurable we call them "beautiful." When the reverse we call them ugly. Thus we speak of a "lovely" pudding or a "sweet" hat, and by an extreme of speech a chemist speaks of a "beautiful" scientific law, the very contemplation of which gives him raptures. And painful and pleasurable emotion are sometimes mingled, like sweets and bitters in taste, so that to sit up on a chilly night with a single candle, to read a ghost story and then peer into the darkness, gives us that compound emotion known as a fearful joy.

It is needful to remark that considering æsthetics simply as the art of rousing emotion, whether pleasurable or painful, this art has in itself nothing to do with morality. You may have an art that is "good" in the sense that it serves a moral purpose or "good" in the sense that it effects some desired end. Thus, for instance, if you say to a boy, "When you tell a lie tell a good one," we mean an effective one. Effective art may, therefore, raise wicked emotions or good emotions, but it is none the less "art." In fact some of the most effective art in the world has been wicked art. The art of refinement in torture is *effective*, though morally bad.

From the definition of æsthetic art as the art which aims at exciting emotion it follows that art is relative. What rouses an emotion of one kind in one man will rouse an emotion of an entirely different kind in another. Thus, for instance, I may write down on a slate:

$$T = \pi\sqrt{\frac{L}{g}}$$

To most of us this represents a mere squiggle of lines rather ugly in appearance, but a physicist says, "How beautiful!" For these marks express the law of the isochronism of the pendulum—the law of harmonic motion, upon which depend the sciences of light and music, of colour, and musical sounds. It is lovely to him, it is ugly to you and me.

So again, a bleeding hand pierced by a dagger may denote faith to one tribe, the punishment of a traitor, blood relationship or a thousand virtues. To us it is a simple anatomical horror. But the bleeding heart of the Virgin Mary, pierced with seven swords to represent the seven sorrows of Mary, is a very common symbol in the Roman Catholic world. It raises the tenderest emotion in the mind of many a grief-stricken mother. To her it is beautiful.

The red heart of Bruce surmounted by a crown was a heraldic emblem which revived the memory of a bloody combat and represented loyalty and faith.

Cloves are pleasant to some people, hateful to others. Yet the art of seasoning a pie is none the less an art. A pie, at the sight of which children's faces brighten, and their emotion finds vent in cries of joy, makes no appeal to the taste of an adult.

The arts which have as their object the stimulation of the emotions have many branches. For instance, you have poetry, prose, literature, painting, sculpture, music, and the rest, and on a lower plane you have the decorative arts, and on a lower plane still the arts of dress, cookery and perfumery, on a lower plane still you have the arts of exciting the bad emotions, and you may even have the art of hanging men with speed and efficiency.

The art of war, as we have also seen, may be raised to cultivate heroism, or prosecuted to the cultivation of lust, rapacity and cruelty.

But in this connection it may be observed that as the aim of all æsthetic arts (derived from a Greek word meaning "to feel") is to stimulate emotions, we might naturally expect that these arts instead of being isolated were very closely connected, so that the principles which succeed in poetry might be also successful when applied to music and painting.

For although in one sense æsthetic art is relative, so that the same thing always operates differently on different people, yet it is easy to see that since we are all human beings, there is likely to be a similarity between the various means of exciting our emotions.

The same medicines which act on men act similarly on many animals Epsom salts is good both for pigs and poultry; and quinine effects a cure of certain diseases in plants no less than in men.

The knowledge that this is so has, however, been fertile in the production of crude and erroneous theories in art.

In ancient days, when the incorrect or Aristotilian method of reasoning prevailed, thinkers were imbued with the

firm belief that Nature proceeded on principles. In this they were perfectly right, but they went the wrong way to find these principles. They formed their theories before they had studied their facts. Thus they said "It is weight that makes a body fall," whence then the more weight there is, the faster it will drop. They never took the trouble to see whether the conclusion harmonized with fact.

So again they said æthetic art has *this* as its principle or *that* as its principle, instead of humbly pursuing the more slow but certain method of first finding out *what* it was that did as a fact rouse emotions before they attempted to explain why it did so.

Thus the South Kensington scientists put forward a theory of colour design on the assumption that the complementary colours of the spectrum produced pleasing effects when put together. If you have purple you must contrast it with yellow; red must go with green, and so on. What nonsense it all was! Nature before, and the Chinese afterwards, showed that no colours can be made to contrast so beautifully as blue and green, or different shades of blue, all of which were condemned by the doctrinaires of the new school.

Therefore, if you want to find what combinations of colours or of lines excite pleasing emotions, *study facts.* Find out what combinations of colours *do* have this effect—when you have got your facts, *then* proceed to formulate your theories.

For theories there are, no doubt, only let us have true theories.

Morris, who did so much excellent work in improving art, was the victim of false theories in almost every direction. For instance, he said that fine art expressed a workman's joy in his work. This, however, is not true except in a very limited sense. There are great works of art such as the Egyptian temples, which were built out of the tears of the workmen, yet they excite our emotions. They may not be moral art, but they are effective art.

From this point of view, then, it would seem that the artist must fit his art to his customer. It is of no use to send the lion and the unicorn to people whose national badge is the eagle, but underlying both these emblems there is of course the emotion of patriotism, which the artist is trying to evoke. There is no use in representing heaven as filled with musicians to people who hate music. Because a barrel organ creates a crowd in the East End of merry dancing children that is no argument for introducing it into a drawing room.

But you will say, "Let us raise the people." I agree, only be patient and do not want to get them all up in aeroplanes.

A mathematician does not commence by teaching the differential calculus to board school children. *Give people what they want*, only try and make it good and wholesome.

Another art-cranky theory is that good art should be all hand-made. This theory would condemn Wedgwood's Etruscan ware, the best art that perhaps the Potteries has ever produced. It would condemn the magnificent collection of Greek gold coins in the British Museum. It would banish almost all silver work. One professor of this school solemnly proposed that we should banish all our present English art, and bring over a number of Hindoos from India to teach us to make Indian ornament. In illustration of his theories he has placed in one of our cathedrals the most awful clock that human eyes have probably ever seen.

But let us as sensible men steer clear of all this nonsense and cant.

If the London East Enders want roses on their plates, give them roses—only try and make them lovely roses. If pretty little children's faces peep out from among the roses so much the better.

It is not the highest art, but if it arouses healthy emotion it is better than giving them some abstract thing that arouses no emotion at all, and which if they admire they admire only for the reason that it looks expensive, or some vulgar reason of that kind.

From this it follows that if the artist is to be an artist, that is to say, if by speech, by writing, by song, by painting, by sculpture, by decoration, he is to arouse emotion and make people *honestly* say "How lovely!" he must be capable of feeling what is lovely himself. He may, like John Leech, be a sad man, and yet draw the drollest sketches, but he must know what drollery is.

Unfortunately this simple fact is too often forgotten. One can imagine a man of the most sordid mind and dissolute life, with a fat cigar in his mouth, over his whisky and water telling his manager to get up a pantomime for children. What sort of a pantomime will it be? How can he promote child-like innocence who does not know what innocence is?—nor, like a play actor, can ever sufficiently understand a virtue to stimulate it.

I grant you that the lives of some of the great painters of sacred pictures were not all they should be, but no one could persuade any reasonable man that Raphael had not a grand conception of the Virgin and Child enthroned in the celestial paradise. How could he have ever excited sacred emotions

in our minds unless he had *felt* them, even if he did not live up to his feelings.

Hence then our artist must cultivate poetry and literature. I don't mean that they are to go and study Shakespeare as it is studied at the universities or board schools, with critical annotations, and essays on the correct texts.

The correctness of the texts, the grammar, the history of the words, even the story do not matter to the artist at all, if he can only catch a little of the full-blooded glowing flow of life that bubbles up in the speeches of Beatrix, the happy simplicity of the songs of Burns, the stately measure of Pope. To artists I would say read poetry; read most what you like most. Don't be always trying to persuade yourself that you like what you think you *ought* to like, and do not read a word of notes, annotations or essays on the poets. They are to art but anatomical dissection. The grandest poet is but a corpse when the annotaters have done with him.

And when you have executed bottles for the Africans, with the good gods enthroned, and wicked men punished, represented on them, when you have painted plates for the ladies with charming landscapes on them, or else entwined beautiful flowers, or in fact anything you find *they* really like, then also give to the rustics their bowls with bright, even gaudy flowers; to the servant maids their nice little bits of jewellery which they shall really admire, then you will have set their feet upon the path of artistic progress, along which they will proceed upwards, and not try like Ixion to reach the skies at a bound.

Moreover, do not despair because a pottery looks an ugly place. A man does not need to inhabit a palace in order to paint heaven; maybe he will paint heaven better in a garret, with no antagonistic ideas to confuse his mind. The grandest pictures come from bare studios. Of course he must see fine things from time to time to inspire his eye, and read fine things to inspire his mind; but a glass of sherry is better than a bottleful.

And lastly, remember that the potter must live, and get hold of the art that is really remunerative. A large part of the work at the potteries is not æsthetic art at all; you can't make much of a pudding basin—you don't pretend to.

But when you are decorating, try and ask buyers what they want, and what they *really* like, just as a cook does, when she is going to cook a dinner; and then use all your art to give them good wholesome food suitable to their age, their sex and their digestion.

Mr. BERNARD MOORE (communicated 4th Feb., 1918):—The aim of a manufacturer should be to please his customers and arouse their admiration for his products. That which will do this in one person will not do so in another. I will give an example. I have devoted a good many years to the study of glazes. If I see evidence in a pretty pot of a difficulty overcome successfully, it gives me pleasure to own the pot. Surely this is an esteemable pleasure—I know it is mine—and this again enhances value of the pot, because more than half the pleasure of possessing pretty things is the power it gives us of showing them to our friends. The particular charm of the pot to me may be quite invisible to that type of artist who lectures us as to what is and what is not correct taste. He may tell me I am quite wrong in admiring the pot. The truth is, he knows only his own language and he cannot read mine. If "sponged ware" and "free brush" decoration please anyone, by all means let them have it, but I do object to anyone trying to prevent me drinking my tea out of dainty china cups because he considers they are in bad taste because they have pretty roses painted on them. I would say one word from the manufacturing side about designers. We must recognise the fact that taste changes; you can have too much of a good thing. The individuality of an artist is always stamped on his work, and the cleverer he is the more this shows. It is a pity, but this is why you find that a mere adapter, who imitates the public taste, is so often much more commercially successful than a clever artist.

Mr. A. E. GRAY (communicated 8th February, 1918):—In bringing the subject of my paper before this Society it was not my object to define art, but to point out the need for equal attention being paid to the claims of art as that of science in relation to pottery.

From a technical point of view I believe we hold the premier position, and progress in that direction may only be possible as the result of more definite concentration on the production of bulk with the aid of organized machinery to eliminate waste of labour and reduce cost.

But on the artistic side of pottery we are agreed that there is great scope for progress, the very breadth of the subject of art and its elusiveness, calls for that careful attention which the industry as a whole has failed to give it.

It is very true that some of our finest paintings have been painted in garrets, but surely that is no argument for retaining the ugliness and squalor of our towns. The garret was a circumstance not favourable to painting, but overcome by the

ideal of the artist: can we say how much better that painting might have been if the artist had been freed from the cramping influence of the garret. Who can say what results may be obtained in an industry the condition and environment of which are clean, healthy and beautiful, the attainment of one ideal but gives birth to another, and progress succeeds progress.

I think I made myself clear that the public must have what it wants, but we must be quite sure we are giving the public what it wants and not the next nearest.

East London demands colour and buys the most of it they can get at the price they are able to pay; but are we quite sure that as they purchase wretched daubs of litho and blown colour, because they can get nothing better at the price, they are therefore satisfied that such goods are the most artistic or even that they are what they really want.

The canal boatwoman wears bright coloured cotton fabrics not because she could not appreciate the better colours in silk fabric, but because she cannot afford silk and must have colour. In pottery it is possible to give all the colour that the East End may crave for and give that colour artistically and cheap.

Tradition may cumber the purchaser as well as the manufacturer, and he will demand the pot dogs until something is placed before him that appeals to him with greater force, because pot dogs were in the old home and might as well be in the new.

To define art even as applied to pottery would be impossible. Going up the lane I am a Pre-Raphaelite, with all the detail of the hedgerow; but when I arrive at the top of the hill I am an Impressionist in the misty loveliness of the outlook. The basalt bowl may be perfect in its right setting, but the setting must be right as well as the bowl.

So art must always be conversant with the intention of the user; we cannot dictate to the West African or other markets if we have no knowledge of the conditions under which the goods are used, but if we have that knowledge then we can surely improve on the lines laid down and not perpetuate ugliness.

As the result of this discussion an Art Section of the Ceramic Society has been formed, of which Major Frank Wedgwood has accepted the presidency.

XV.—Sur les propriétés réfractaires de la Magnésie.

MM. H. Le Chatelier et B. Bogitch.

La magnésie, dont les propriétés réfractaires ont depuis longtemps été signalées par M. Schloesing, est aujourd'hui couramment employée à la fabrication de materiaux réfractaires très réputés. Leur emploi dans les fours d'aciérie s'est rapidement généralisé parallèlement au développement des procèdés basiques. Dans ce mode de traitement, l'affinage du métal est obtenu en présence d'un laitier riche en chaux, c'est à dire très basique, d'où le nom du procédé. Grâce à cette teneur élevée en chaux, on peut éliminer de la fonte, non seulement le carbone, le silicium et le manganèse, mais encore le phosphore qu'il serait impossible de faire disparaitre en présence d'une scorie riche en silice.

L'emploi des laitiers basiques serait impossible dans un four dont les parois seraient entièrement construites en briques siliceuses on argileuses ; ces matériaux se dissoudraient trop rapidement dans le bain calcaire. Les briques de magnésie, au contraire, constituées elles mêmes par un oxyde basique, résistent parfaitement dans ces conditions. Dans tous les fours basiques, la partie inférieure des parois verticales et souvent la sole elle même sont construites en magnésie. La voute, par contre, est toujours faite avec des briques de silice.

Les briques de magnésie passent pour être très refractaires ; la magnésie pure fond seulement vers 2,400° c'est à dire à une température supérieure de 700° à celle des fours d'aciérie ; mais la magnésie employée pour la fabrication des briques n'est jamais pure. Elle renferme des proportions variables d'oxyde de fer qui colorent plus ou moins fortement les briques en brun. Ce fer se trouve dans le minerais à l'ètat de carbonate de fer isomorphiquement mèlé au carbonate de magnésie naturel. Elle contient encore de la silice et un peu d'alumine provenant soit de silicates magnésiens associés au carbonate, soit des cendres du combustible employé dans la

première cuisson. Toutes ces impuretés augmentent nècessairement la fusibilité de la masse.

Il nous a paru intéressant d'étudier les propriétés réfractaires des briques de magnésie comme nous l'avions fait précédemment pour celles d'argile et de silice. La méthode expérimentale employée a été la même que celle de nos premières recherches.

Nous donnerons par la même occasion des résultats relatifs à une brique de fer chrômé. On emploie ces briques dans la construction des fours pour séparer les briques de magnésie de celles de silice. Le contact direct de matériaux basiques et acides provoquerait leur fusion mutuelle. Le fer chrômé au contraire ne reagit ni sur la silice, ni sur la magnésie.

Les matières essayées ont été, soit les briques industrielles, soit des échantillons prèparés au laboratoire. Pour obtenir un terme de comparaison, on avait essayé de préparer un bloc de magnésie très pure en fondant au four électrique de la magnésie precipitée ; mais à la haute température nècessaire pour cette fusion, la chaux des parois du four et les impuretés qu'elle renferme se volatilisent et vont souiller le produit fondu. On a obtenu ainsi une matière renfermant seulement 94 centièmes de magnésie et tout juste comparable aux bonnes briques de fabrication industrielle.

Nous donnerons dans un premier tableau la liste des produits essayés, dans un second, leur analyse chimique et dans un troisième, leur résistance à l'ècrasement mesuré à différentes températures.

Liste des produits essayés.

I. Brique de Styrie, cuite à 1,450°, fabriquée en 1890, qualité normale.

II. Bonne brique d'Eubée, fabriquée en 1910.

III. Brique *G*, bonne fabrication actuelle.

IV. Brique *B*, mèdiocre, addition dans le pâte de 3 centièmes de pyrite grillée.

V. Magnésie pure fondue au four èlectrique et souillée par cette opération.

VI. Matière première des briques *B*, agglomérée au foui èlectrique.

VII. Brique de fer chrômé.

ANALYSE CHIMIQUE.

	I	II	III	IV	V	VI	VII
Magnésie	86·7	93·4	89·4	81·2	93·7	88·5	12·3
Chaux	1·0	3·7	4·5	4·8	2·7	4·5	5·8
Oxyde de fer (Fe_2O_3)	6·0	0·5	1·1	4·2	0·3	1·4	15·5 (FeO)
Alumine	0·6	0·2	0·8	1·0	1·1	0·0	10·9
Silice	6·7	2·8	4·2	8·8	3·2	6·5	4·7
Oxyde de chrôme ..	—	—	—	—	—	—	50·0
„ de Manganèse	—	—	—	—	—	—	1·5
Total ...	101·0	100·6	100·0	100·0	101·0	100·9	100·7

RESISTANCE A L'ECRASEMENT EN KG. PAR CM².

Température	15°	1000°	1300°	1500°	1600°
I	145	85	66	3·6	1·8
II	420	—	—	185	8
III	390	—	—	> 90	4·8
IV	230	—	—	16	3·5
V	—	—	—	> 90	6·6
VI	530	—	—	—	3·5
VII	260	120	6	2	1

Pour les deux premières briques, celles de Styrie et d'Eubée, les expériences ont été en rèalité plus nombreuses que celles portées au tableau ci-dessus. Elles ont permis de tracer la courbe complete des résistances mècaniques (Fig. 1), les deux courbes sont caractérisées par une chute brusque de résistance à l'écrasement qui se produit entre 1,300° et 1,400° pour la brique de Styrie, la moins pure des deux, entre 1,500° et 1,600° pour celle d'Eubée. Toutes les briques de magnésie présentent cette chute brusque de résistance à une température plus ou moins élevée suivant leur degré de pureté. Tout se passe comme si, à une certaine température, les matières étrangères fondaient brusquement de façon à laisser les grains de magnésie isolés dans un magma fondu. Ils sont alors dans le même état que du sable humide et ne possèdent plus qu'une résistance mécanique très faible. Les meilleures briques de magnésie présentent à 1,600° une résistance à l'ècrasement bien inférieure à celle des bonnes briques de silice. De plus, à ces températures élevées la déformation des

briques de magnésie se fait comme pour celles d'argile, elles cèdent progressivement au lieu de se rompre brusquement comme les briques de silice. Pendant le réfroidissement la matière ècrasée se ressoude et reprend sa dureté après la solidification du magma fondu.

Ces résultats expliquent comment les briques de magnésie résistent moins bien dans les parois des fours que celles de silice, bien que leur température de fusion, lorsqu'on l'observe en dehors de tout effort mècanique, soit très notablement supérieure, 2,050° au lieu de 1,750°.

L'allure de la chute de résistance dans la brique de fer chrômé est analogue à celle des briques de magnésie, mais avec une température beaucoup plus basse pour la perte rapide de solidité, 1,100° au lieu de 1,350° à 1,550° suivant la puretè de la magnésie.

[TRANSLATION BY J. A. A.]

MAGNESIA, the refractory properties of which were long ago pointed out by Schlœsing, is to-day readily employed in the manufacture of refractory materials of high repute. Their employment in steel furnaces has rapidly become general, parallel with the development of basic processes. In this mode of treatment, the refining of the metal is obtained in the presence of a slag rich in lime, that is to say, very basic, whence the name of the process. Thanks to this high content in lime, there can be eliminated in the smelting not only carbon, silicon, and manganese, but moreover phosphorus, which it would be impossible to cause to disappear in the presence of a slag rich in silica.

The employment of basic slags would be impossible in a furnace the walls of which were constructed entirely of silica bricks or clay bricks, these materials dissolving very rapidly in the calcareous bath. Magnesia bricks, on the contrary, themselves constituted of a basic oxide, resist perfectly in these circumstances. In all basic furnaces the lower part of the vertical walls, and often the sole itself, are constructed of magnesia. The arch, as a set-off, is always made with silica bricks.

Magnesia bricks are considered to be very refractory; pure magnesia melts only about 2,400°, that is to say, at a temperature 700° above that of steel furnaces; but magnesia employed for the manufacture of bricks is not always pure.

It includes variable proportions of iron oxide, which colours the bricks more or less strongly brown. The iron is found in the mine in the state of carbonate of iron, isomorphously mixed with the natural carbonate of magnesia. It contains moreover silica and a little alumina arising either from magnesian silicates associated with the carbonate, or from ashes of the fuel employed in the first burning. All these impurities necessarily increase the fusibility of the mass.

It appeared interesting to us to study the refractory properties of magnesia bricks like we had done previously for clay bricks and silica bricks. The experimental method employed has been the same as that of our former researches.

We will give on the same opportunity results relative to a chromite brick. These bricks are employed in the construction of furnaces for separating magnesia bricks from silica bricks. Direct contact of basic and acid materials would promote their mutual fusion. Chromite, on the contrary, reacts neither with silica nor magnesia. The substances tried have been either industrial bricks, or specimens prepared in the laboratory. In order to obtain a term for comparison we tried to prepare a block of very pure magnesia by melting precipitated magnesia in an electric furnace; but at the high temperature necessary for this fusion the lime of the furnace walls and the impurities which it included volatilise and go to contaminate the melted product. We thus obtained a substance including only 94 per cent. of magnesia and exactly comparable to good bricks of industrial manufacture.

In a first table we will give the list of products investigated, in a second their chemical analysis, and in a third their resistance to crushing, measured at different temperatures.

List of products investigated.

I. Styrian brick, burned at 1,450°, made in 1890, quality normal.

II. Good Eubœan brick (Greek), made in 1910.

III. Brick *G*, good present-day manufacture.

IV. Brick *B*, ordinary, addition in the paste of 3 per cent. roasted pyrites.

V. Pure magnesia melted in an electric furnace, and contaminated by that operation.

VI. Principal substance of bricks *B*, agglomerated in the electric furnace.

VII. Chromite brick.

CHEMICAL ANALYSIS.

	I	II	III	IV	V	VI	VII
Magnesia	86·7	93·4	89·4	81·2	93·7	88·5	12·3
Lime	1·0	3·7	4·5	4·8	2·7	4·5	5·8
Iron Oxide (Fe_2O_3)	6·0	0·5	1·1	·2	0·3	1·4	15·5 (FeO)
Alumina	0·6	0·2	0·8	1·0	1·1	0·0	10·9
Silica	6·7	2·8	4·2	8·8	3·2	6·5	4·7
Chromium oxide ...	—	—	—	—	—	—	50·0
Manganese oxide ...	—	—	—	—	—	—	1·5
Total ...	101·0	100·6	100·0	100·0	101·0	100·9	100·7

RESISTANCE TO CRUSHING (KILOG. PER SQ. CM.).

Temperature	15°	1000°	1300°	1500°	1600°
I	145	85	66	3·6	1·8
II	420	—	—	185	8
III	390	—	—	> 90	4·8
IV	230	—	—	16	3·5
V	—	—	—	> 90	6·6
VI	530	—	—	—	3·5
VII	260	120	6	2	1

For the first two bricks (Styrian and Eubœan) the trials have been in reality more numerous than those contained in the above table. They have allowed the complete curve of the mechanical resistances (Fig. 1) to be traced. These two curves are characterized by an abrupt fall in resistance to crushing, which is produced between 1,300° and 1,400° for the Styrian brick, the less pure of the two, between 1,500° and 1,600° for the Eubœan brick. All the magnesia bricks present that abrupt fall in resistance at a temperature more or less elevated according to their degree of purity. Everything happens as if at a certain temperature, the foreign substances melt suddenly so as to leave the magnesia grains isolated in a melted magma. They are then in the same condition as wet sand and possess no more than a very weak mechanical resistance. The best magnesia bricks present at 1,600° a resistance under load much inferior to that of good silica bricks. Moreover, at these high temperatures deformation of magnesia bricks takes place as for clay bricks, they yield progressively instead of breaking suddenly like silica bricks.

During the cooling the crushed material becomes cemented together again and resumes its hardness after the solidification of the melted magma.

These results explain why magnesia bricks offer less resistance in the walls of furnaces than silica bricks, although their temperature of fusion, when it is observed outside of all

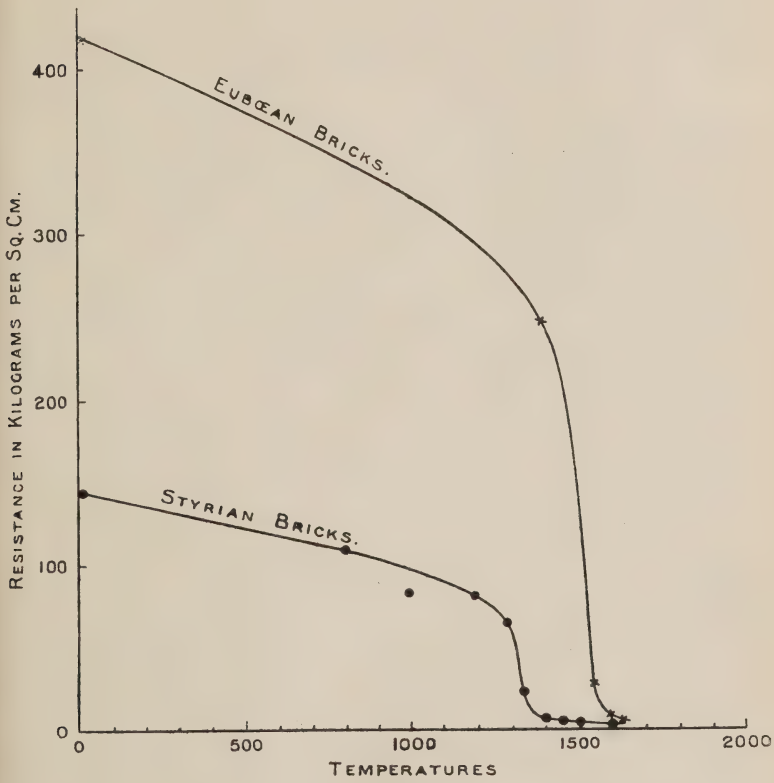

Fig. 1.

mechanical effort, is very notably superior, 2,050° instead of 1,750°

The velocity of the fall in resistance in a chromite brick is analogous to that of magnesia bricks; but with a temperature much lower for the rapid loss of stability, 1,100° instead of 1,350° to 1,550°, according to the purity of the magnesia.

XVI.—The Estimation of the Proportions of Quartz, Tridymite, etc., in Silica Bricks.[1]

By Alexander Scott, M.A., D.Sc.

THE methods which are available for the estimation of the relative amounts of the components of such mixtures as refractory materials are dependent on one or other of the following, (*a*) chemical analyses, (*b*) specific gravity determinations, (*c*) direct measurements. In the case of silica bricks, the first of these is of little use, as quartz, tridymite and cristobalite, the three chief constituents, have the same chemical composition. Hence a bulk analyses gives no indication as to the relative proportions of these, while no methods of "rational analyses" depending on differential solubility, etc., have been devised.

If only two constituents such as quartz and tridymite were present, a direct determination of the specific gravity of the finely-ground material would give a fairly accurate value of the relative amounts, but the accuracy diminishes rapidly as the amount of impurity increases. As silica bricks always contain a fair proportion of impurity, partly in the original rock and partly in the bond, this method yields only very approximate results. A similar objection applies to the method in which the material is crushed and the various constituents separated by means of liquids of high specific gravity. Unless the grinding be carried to an extraordinary degree of fineness, homogeneous particles are not obtained, while in addition diminution in grain size is accompanied by a great increase in the time which is required for the settling of the particles in the liquid.

Direct measurement, however, provides a comparatively rapid and accurate method which involves no particular manipulative skill and can be carried out with no apparatus beyond a microscope and thin sections of the materials to be examined.

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1 I have been asked so many times for a rapid easy way of approximately estimating the progress of the conversion of quartz into tridymite or cristobalite that I asked Dr. A. Scott if he would be good enough to write a short note, suitable for those who have not specialized in microscopic work, on this subject. I also said that the note was to aim not so much at originality as at ability. Specific gravity has been previously used for this purpose. *Trans.* **15**, 77, 1916. The method would not be applicable if impure material were in question.—Editor.

The earliest form of this method, involving the use of a microscope, is due to Sorby (*Phil. Mag.*, 4th Ser., Vol. XI., pp. 20-33, 1856), and consisted in drawing on paper the outlines of the constituents of several typical "fields" by means of a camera lucida, marking the different constituents in the same way and finally cutting out the various parts and weighing them in an ordinary balance. In order to obtain accuracy, it is necessary to take a number of different fields, and when the material is fine-grained the process is somewhat tedious. Microphotographs have been used in place of camera lucida sketches, while the weighing has also been substituted by direct areal measurement with a planimeter.

Rosiwal (*Verhand. geol. Reichsanstalt*, 1898, pp. 143—75) further improved the method by introducing linear measurement in place of areal, deriving the proportions by measuring the intercepts which the particles of each constituent made with a number of arbitrary lines. That these intercepts are directly proportional to the volume of the constituents, provided a sufficient number of measurements are made, has been proved rigorously by Rosiwal (*loc. cit.*). A geometrical proof has been given by Lincoln and Reitz (*Jour. Geol.*, VIII, 120—39, 1913). The accuracy of the method has recently been proved beyond doubt in the case of a series of complex igneous rocks (Tyrrell, *Quart. Jour. Geol. Soc.*, LXXII, p. 111, 1917). The results obtained from measurements made by Rosiwal's method were compared with those got from a series of chemical analyses made by the writer, and the agreement between the two indicates the great utility of the method.

In the case of silica bricks the method is difficult to apply if the proportions of all the constituents are required, owing to the fineness of grain of the tridymite and cristobalite, but it has been found to give excellent results in the estimation of the proportion of quartz remaining unconverted after any particular treatment. As the chief volume change in the brick is due to the transformation of the quartz into the other forms, the amounts of the latter relative to each other are of little importance compared with the relative amount of unaltered quartz.

The objective used depends on the grain size of the quartz in the original ganister, but it will generally be found that a ¼ in. (6 mm.) or ½ in. (12 mm.) objective will be suitable. It is also advisable to have the thin section between crossed nicols as the quartz can then be readily distinguished by its interference colour, generally yellow, compared with the grey of tridymite or cristobalite. The clear surface of the quartz also serves to distinguish it. A series of lines (6 to 8) is drawn

on the slide parallel to one edge of the glass, and a second series perpendicular to the first. The slide is then adjusted by means of the mechanical stage so that one line coincides with one of the crosswires of the eyepiece, the whole part of the section along that line is made to traverse the field of view by means of the mechanical stage, and the length of intercept of each quartz crystal measured. The measurement may be done by means of a micrometer eyepiece, but after a little practice good results can be obtained by dividing the crosswire into ten parts "by eye" and estimating the intercept of each crystal in terms of these "tenths" as units. The total intercept of the section along the line is measured in terms of the same units, but as an occasional "hole" may occur the latter must also be measured and deducted. The same procedure is carried out along the other lines parallel to the above and also in a perpendicular direction along the second set of lines by means of the other motion of the stage. The intercepts made by the quartz crystals are then added together and divided by the sum of the intercepts made by the section along the two sets of lines. The amount of the other constituents can be obtained by difference, but the result may be verified by direct measurements similar to those obtained for quartz.

The table gives the results obtained in the case of a brick which after kiln-burning had been heated for several days at 1,400°, *a*, *b*, *c*, being the results obtained from three traverses, and *d*, the totals from 12 traverses; *e* gives the totals obtained from 12 traverses of another thin section of the same brick.

	Quartz as Measured	Other Constituents Measured	Other Constituents By Difference	Total
a	41	139	138	179
b	24	117	119	143
c	27	121	117	144
d	357	1401	1392	1749
e	421	1562	1571	1992

The proportions of unaltered quartz are therefore 20·4 and 21·1 per cent. respectively for the two sections, the difference between the two estimations being therefore ·7 per cent.

In order that the results should have a probable error of 1 per cent. or less it is advisable to measure intercepts totalling about 1,500 units. The results, of course, give the proportions by volume. As stated above, the relative amounts of tridymite, cristobalite and matrix cannot be estimated by this method

with any degree of accuracy, but in certain cases it has been found possible to obtain consistent results with bricks which have been in use for long periods. For instance, a brick which had been heated to 1,550° C. for over a year, and which showed no contamination by foreign material, gave the following results:—Tridymite 91·4 per cent., cristobalite 1·9 per cent., matrix (clear glass) 6·7 per cent., quartz absent.

After some practice, the proportion of quartz in a brick can be estimated, with a probable error of less than 1 per cent., in about an hour

XVII.—Manufacturing Refractory Materials with Fused Bauxite.

By Noel Lecesne.

IT is well known that the most refractory products employed in the construction of furnaces undergo either shrinkage or expansion, according to their composition, when exposed to a higher and more prolonged temperature than that at which they were baked, which is generally the case, and, independently of their destruction by mechanical means, their duration is limited to their fusing at sufficiently high temperatures, as these temperatures are themselves limited by the insufficient resistance to heat of these products: chemical influences, as well as sudden changes of temperature, are often even more disastrous than heat. Among all refractory products natural corundum would take the first place, if its high price, as well as its scarcity, did not render its employment prohibitive, save perhaps for small ovens.

Up to the present, people have contented themselves with employing alumina in its most natural form, represented by bauxite, called white bauxite. The alumina contained in this kind of bauxite constitutes effectively the refractory element "par excellence" of refractory matter employed in the construction of ovens. However, the scarcity of this kind of bauxite, characterized by its richness in alumina and its poorness in iron, limits also its use.

Products into which bauxite enters in proportions of about 60 per cent. alumina and 33 per cent. silica, approach the composition of proto-silicate of alumina, and constitute refractory products, resisting easily ashes and chemical influences, but offering little resistance to sudden changes of temperature In order to avoid this drawback it has been tried to increase the proportion of alumina, but the products, when submitted to high temperatures undergo progressive and considerable shrinkage proportionately to their richness in alumina it even frequently happens that those parts most exposed to fire become transformed into corundum, the density of which is nearly double that of bauxite, whence the shrinkage undergone by the alumina of even the most calcined bauxite. By observing the formation of this corundum on products rich

in alumina it was thought preferable to fuse the bauxite directly and transform it into corundum, intended to replace hydrated alumina in refractory matter in which alumina enters as an essential element, the alumina being thus absolutely and indefinitely stabilized. But bauxite cannot be fused, commercially, at any of those temperatures obtained by means of fuel, in industrial and metallurgical furnaces, without the presence of fluxes which lower its fusing point, and besides, bauxite fused by means of flux retains all or part of this last, thus it follows that its refractory properties are considerably reduced, if not annihilated. Moreover, and this is of capital importance, as the fusing point of the bauxite is lowered by the presence of flux—it has been lowered to 1,200° C.—the temperature realised is insufficient to insure the vaporization of the impurities of the bauxite, notably the iron and silica, and their expulsion, if necessary. And if the corundum obtained by the fusing of bauxite with flux be excellent for the manufacture of, for instance, polishing products, it would not be suitable for the preparation of a refractory product, practically infusible, except by blowpipes utilizing compressed gas, or by the electric furnace, which should be the characteristic of the corundum considered in the author's patent. (See French patent No. 471,513, July 11th, 1914.)

This patent concerns a process for the obtaining of fused bauxite, simple, economical and easy to carry out, without employing flux, based upon the transformation of a mixture, in suitable and sufficiently intimate proportions, of bauxite and anthracite, into aluminium carbide, which is burnt as soon as formed: the operation is conducted in a tub oven, lined with firebricks, into which air is blown by compression. The charge is brought to incandescence of the nature of that of alumino-thermic reactions, and the impurities in the bauxite are eliminated, the silica in the form of white vapour, and the sesquioxide of iron by reduction, with expulsion of the iron out of the oven, and production of magnetic oxide. When all the bauxite is fused, the blowing is continued in order to consume the excess of anthracite and cool the mass, which is then simply discharged. Finally the corundum obtained is crushed and agglomerated preferably with finely ground raw bauxite, and then fired.

It is preferable to employ, instead of dry bauxite, bauxite saturated with its own natural water, in order to effect the granulation of bauxite and fuel directly in the oven, and to avoid the inevitable formation of dust in the mechanical grinding, previous to its introduction into the oven: the air pressure would project this dust out of the oven, whence an important

loss of coal and bauxite. Moreover, the labour necessitated by previous crushing is thus eliminated, and an appreciable economy thereby obtained.

The following example will render the invention comprehensible:

EXAMPLE:—Mix 500 kilos. of anthracite with 1,500 kilos. bauxite, taken as it comes, saturated with its own natural water, of no commercial value, abundant in the South of France; the alumina of this bauxite exceeds 60 per cent., but its high percentage of sesquioxide of iron, which amounts to nearly 10 per cent., renders it difficult to utilise as refractory matter, and its silica, which also attains nearly 10 per cent., renders it useless for the manufacture of alumina. The anthracite selected is also taken as it comes to hand, of medium quality, and may be replaced by anthracite coal of good quality; but the *Swansea* anthracite, far purer, gives better results in every respect.

This mixture is loaded all at once into a tub oven, lined with refractory bricks, for which fused bauxite is used as soon as this product can be substituted for ordinary refractory matter; the oven has been previously ignited with a charge of anthracite deducted from the 500 kilos. of the mixture. The air is blown in by compression, at an initial pressure of 50 grammes (about 1/2 mètre of water), capable of attaining 500 gr., according to the height of the charge; it is rarely necessary, however, to go beyond 200 gr., even for a heavy charge.

The temperature rapidly rises; the bauxite bursts and crumbles of itself, from the fact of the sudden evaporation of its moisture, and the anthracite crackles and disintegrates. The mixture, stirred up by the gas, becomes more intimately mixed and is progressively transformed into aluminium carbide, which is consumed as it forms; the temperature mounts to such a degree as to carry the whole charge to an incandescence identical with that of alumino-thermic reactions.

At this stage, the impurities contained in the bauxite begin to be eliminated. The vaporized silica quits the oven in the shape of a thick white smoke, and the sesquioxide of iron is reduced; the iron comes to boiling point and is projected outside in the form of brilliant sparks, which are converted into magnetic oxide on coming into contact with the air.

This reaction gives rise to a sudden release of heat, sufficient to raise the temperature of the mass to more than 3,000° C. As soon as the incandescence begins to diminish and turns to a dazzling white, to become afterwards yellow, the reaction is over and all the bauxite is fused; the blowing is continued, so as to consume the excess of combustible and cool the mass, in order to effect its discharge, which presents no difficulty. Finally, the mass is crushed, conglomerated, moulded, dried and baked, as in the case of calcined bauxite.

It is advantageous to conduct the operation rather quickly, so that it shall not last more than three hours, in order to obtain, on one hand, the porosity necessary to the desired product, and on the other, the enclosure in the fused mass of a small quantity of disseminated anthracite. Effectively, the presence of this combustible facilitates the eventual crushing, which would otherwise be very difficult, on account of the hardness (bordering on 9) of the product obtained; it also facilitates the binding of the crushed matter in the undermentioned cases.

When the operation has been properly conducted, the corundum obtained is porous enough to weigh, after crushing, only 1,500 grammes per litre, and in any circumstances never more than 1,700 grammes per litre, which classes it among

refractory products of normal, even light, weight. This corundum retains, besides the particles of anthracite, free from volatile matter, a small quantity of silica, in the form of fused quartz grains, and a few grains of metallic iron: the percentage of alumina fluctuates between 80 per cent. and 90 per cent., according to quality of bauxite and anthracite employed. If necessary, after crushing, by means of piston vats, the coal and grains of silica can be removed; it is generally unnecessary, however, for the corundum combines with difficulty with amorphous silica, and not at all with the grains of fused quartz, even at a high temperature, except in presence of a powerful flux. The grains of metallic iron, as well as the few particles of magnetic oxide of iron, can be removed by electro-magnetic separation when necessary.

The economical crushing of this corundum is attained by means of, first, crushing by a stone-breaker, having very short but rapid movements, finishing off with cylinders of synchronous velocity. The product of this style of crushing gives an average of fine and equal grains, well suited to its destination. The whole can be sifted through a sieve with meshes of 4m/m. It can also be sifted, according to requirements: for instance, remove all or part of the grains having from 1 to 4m/m., class and utilize them for cemented pavings and flagstones, in place of carborundum, the price of which is high and which they very economically replace.

To obtain refractory products, in which this corundum is substituted for calcined bauxite, and in order to attain far greater refractoriness, the binding, moulding, drying and firing are carried out as for calcined bauxite, but diminishing the proportion of the binder or at least its humidity.

Non-porous matter, the refractoriness of which approximates to 2,000° C., can be obtained by mixing this corundum, ground, freed from coal and iron, with crushed quartz, triturated with water and a little quicklime; the silicate of lime necessary for the binding is formed, but no silicate of alumina, for the two products, when in presence of one another, do not combine. The porosity of the corundum balances the expansion when this happens progressively under the influence of prolonged high temperatures.

Porous pottery, offering a maximum of refractoriness, and admitting of new industrial applications, can be obtained by mixing the corundum with raw bauxite, very finely ground, which is economically obtained by percussion mills. Casts of this composition acquire great hardness: they are infusible. Raw bauxite here serves as binder, the proportions of the mixture may vary according to requirements, from three

volumes of corundum for one volume of raw bauxite, to nine volumes of corundum for one of raw bauxite.

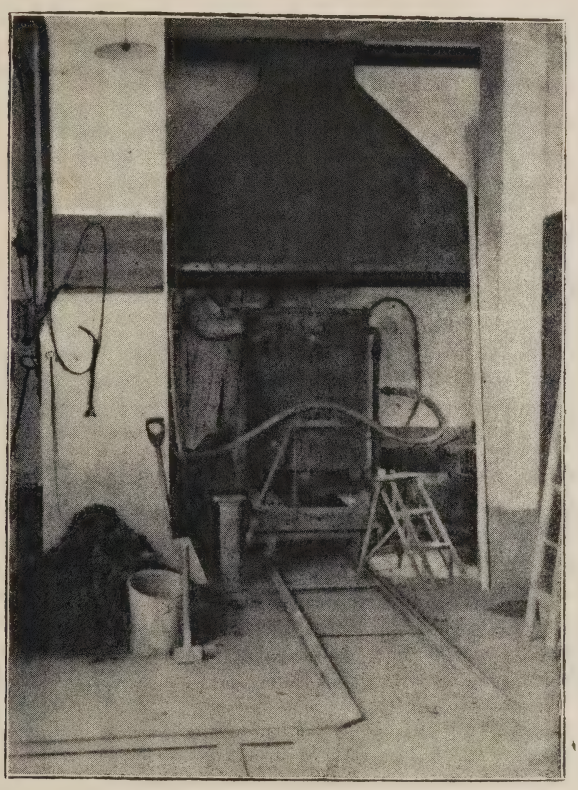
The bauxite, composition of which is above indicated, is quite sufficient to obtain good results. For instance, to obtain practically infusible refractory products not readily deformed, at temperatures even higher than 2,000° C., nine volumes of corundum are mixed with one volume of bauxite, and the whole is so damped as to permit of moulding under great pressure. After complete desiccation, the moulded bricks or objects are baked or fired like any other refractory matter, and in the same conditions. These bricks and blocks have the property of condensing and burning combustible gases in their pores, and of concentrating heat to such a degree that the presence of the anthracite remaining in the corundum suffices to engender during the firing a reaction resulting in the crystallizing of the raw bauxite added as binder, so effectively that finally the grains of corundum are welded together, forming bricks and blocks resisting admirably all pressure. They have, after baking, the appearance and porosity of emery or corundum wheels, used for industrial purposes; they can, moreover, be substituted for them in many cases, care being taken to mix and mould them accordingly.

The porosity of bricks obtained from this corundum and their property of burning combustible gases in their pores, in concentrating heat, allow of the obtaining of very high temperatures, at the same time reducing the cost of fuel. In the case of ovens in which the heating takes place by direct contact of the bodies to be heated with the fuel and in which the lining is formed of corundum bricks, the temperatures attain and surpass 2,000° C. if the air be furnished at from 50 to 100 grammes pressure. The best effects are obtained in gas ovens, liquid fuel ovens, and those called "bakers' ovens." In these ovens, the refractory blocks not being in contact with the slag of solid fuel, their duration is practically unlimited.

The resistance of crucibles made of corundum is quite remarkable; the maximum of useful effect is obtained as well as very long duration, in employing porous crucibles, made entirely of fused bauxite, with a thin internal lining; the fusion of the metal is considerably accelerated.

This corundum is very suitable for the manufacture of bricks entering into the building of furnaces provided with apparatus for the re-heating of air for combustion, of regenerators or recovering apparatus; the open trellis of regenerators of the Siemens type can thus acquire unlimited duration, joined to extreme capacity for accumulating heat. The same applies to boiler masonry.

It will be easily understood that to use the described process, bauxite may be of no matter what composition or percentage, and that anthracite, preferably employed, may be replaced by other fuel, although the final product be far from equalling that obtained with anthracite. Finally, it is obvious that the proportion of the mixture indicated in the above



Furnace in use.

example may be varied, according to the percentage of the bauxite in iron, silica, combined water and humidity, and according to the quality of the anthracite employed. Again, the bauxite can be damped, if necessary, by watering, always for the purpose of ensuring its bursting and granulating in the oven itself, and to do away with the mechanical crushing.

with all its consequences, as also the intimate mixture of the bauxite with the fuel, before its introduction into the oven.

On account of great difficulty encountered in the construction of the cupola intended for the fusing of bauxite I was obliged to procure, in a coal-skip factory, those elements which enabled me to construct one myself. In

Furnace with Block just discharged.

England, therefore, "a fortiori," identical elements can be found, enabling the rapid construction of similar ovens. The coal skip is of about 600 litres capacity, made of sheet-iron of 4m/m. thickness. The bottom, reinforced, is perforated with holes of 5m/m. and is about 450m/m. diameter. Underneath this perforated bottom is fixed, with bolts, the air-box, this

last joined by a flexible pipe to a Root's blower, with a delivery according to speed, of from 4 to 10 cubic metres of air per minute, and a pressure between 350 and 550m/m. water. The skip is lined with good ordinary refractory bricks. This refractory lining is very strongly fixed in place by three iron plates with bolts. When the operation is terminated the skip, tilted up by two men, rests on a little groundwork, and the block is withdrawn by means of hooks. The internal height of the oven can be two or three times the interior diameter, measured between the refractory casing, instead of being only a little greater, as in the illustrations.

Note on the Industrial Execution of the English Patent No. 17,289/16.

By N. Lecesne.

Experience has shown that this patent is well grounded. Practically, common bauxite will have to suffice, as bauxite rich in alumina is dear, but whatever the composition of the bauxite, it has a valuable quality, that of never, once fired, undergoing either shrinkage or deformation.

Bauxite of good quality, the same bauxite in its natural state serving as a binder, gives after firing at 1,500° to 1,600° C., refractory matter whose refractoriness oscillates, according to its richness in alumina, between 1,800 and 1,900° C.

Tests carried out on the 10th March, 1917 (under the name of Corindite—trade mark), at the laboratory of the Conservatoire Nationale des Arts et Métiers, in Paris, controlled and attested by the Ministère de l'Armement, have demonstrated a refractoriness to 1,960° C.

A mixture of 85 per cent. fused bauxite with 15 per cent. raw bauxite, is a proportion giving good results for all bauxite, in general, and Irish bauxite in particular. Whatever the amount of combined water in the bauxite, the working has proved that four times more fused bauxite is always obtained than the quantity of anthracite employed.

It has been possible to reduce the air blowing pressure to less than 50 grammes; practically all cupola blowers can be used. The fusing oven is itself a cupola, as may be seen by the drawings and photographs. The plan gives the dimensions of an oven producing about 260 kilos. of fused bauxite per charge, with 58 kilos. of anthracite and 250 to 300 cubic

mètres of air blown per hour at 30–50 grammes pressure. A good part of this air serves to prevent the mass from adhering to the sides of the oven. 450 kilos. of bauxite and 66 kilos. of anthracite are employed, and the oven is charged in the following manner:—

Two hundred kilos. of bauxite pass through a mill of the same construction as a coffee-mill. The biggest grains are of the size of nuts of 15 to 20 m/m. in diameter From these 200 kilos. ground, are separated about 30 kilos. of the biggest grains, by means of a sieve; these are emptied into the bottom of the oven, on to the perforated grid, to a thickness of about ten centimètres, which will protect the grid against all overheating, and without which protection it would melt.

The cylinder *p* is placed on these nuts and in the centre of the oven, and between this cylinder and the sides of the oven, up to about two-thirds of the height of the cylinder, is thrown the remains of the 200 kilos., crushed in the mill, after having sprinkled them in such a way that the dust will not rise with the blowing (better too much wetting than not enough).

Then, by gentle blowing of air, a small charcoal fire is ignited, upon which is afterwards placed eight kilos. of anthracite, and the blowing is slightly accelerated.

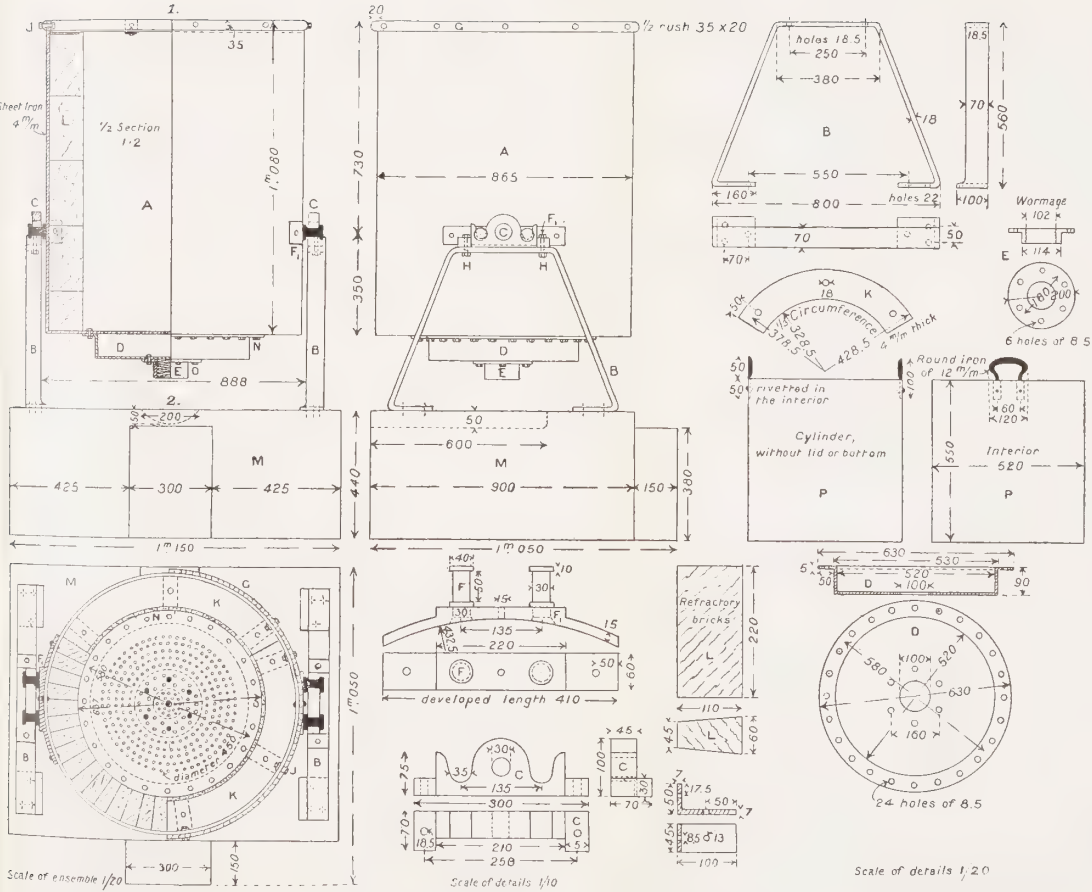
As soon as the anthracite is fully ignited begins the pouring on to it of the charge, composed of 250 kilos. of bauxite in lumps, broken up by a stone-breaker, and well sprinkled, and 58 kilos. of anthracite, either in lumps of the same size or in grains, the whole previously mixed on the ground with a spade.

Each time the charge thus thrown in should not exceed two-thirds of the cylinder, so as to allow of the easy lifting of the latter 15 to 20 c/m. each time. When lifted, by balancing it from side to side, from 15 to 20 c/m., 15 to 20 c/m. of the charge is added to the centre, and another 15 to 20 c/m. of the milled bauxite is added between the cylinder and the oven sides and so on, until the oven is completely full.

This oven works without a lid and as far as possible in the open air, or under a chimney hood like that seen in the first photograph.

The small quantity of charge and milled bauxite that finds no room in the oven is put on one side for a subsequent charge, unless it is preferred to mix and throw them into the oven an hour later, to replace the subsided charge, which is what we are accustomed to do.

As soon as the oven is loaded the air is blown at 250–300 cubic métres per hour, at a pressure of 30–50 gr., until the end of the operation.



For Lescene's Paper.

During 60 to 80 minutes the bauxite gives out steam with explosive violence. Afterwards the gas inflames above the oven, the silica begins to emerge and continues so to be emitted during about 60 minutes. During this last hour the bauxite really and audibly *boils*.

A poker plunged into this boiling bauxite comes out covered with a sleeve of corundum, thus incontestably demonstrating the fusing and the vitrification of the bauxite.

The temperature has been sufficiently high to melt part of the milled bauxite placed as lining. This explains why the block weighs more than the 250 kilos. of bauxite mixed with the coal.

It will be observed that the only melted part of the lining is that in immediate contact with coal and the vaporized and superheated steam of the combined water.

The blowing is continued until complete combustion of the last free particles of coal, and the cooling of the mass.

The oven is then inverted. By drawing it with hooks the block of fused bauxite slides on the remaining lining and falls to the ground; what remains of the lining serves for the next operation.

It is then seen that the grid and the sides of the oven have been thoroughly protected and that the oven is practically new.

The operation, charging, fusing, cooling and discharging, lasts, in all, as will be seen, about three hours. Several operations can therefore be carried out in a day, the quantity thus produced will suffice for all tests and trials.

Being unable to procure rapidly the necessary metal to construct my ovens I transformed what coal-skips I could get into ovens.

XVIII.—Question Box.

Question:—What is the cause and cure of the Small Light Patches on Surface of Dark Green Glazed Tile? (Sample submitted.)

Opened by C. E. RAMSDEN.

1. *Description of the Defect.*—The spots, when examined through a magnifying glass, do not appear to be crystalline in structure; but it is possible that under a higher power lens they may be shown to be aggregations of small crystals. The surface is quite smooth, but the defect is sufficient to cause the tiles to be classed as seconds.

A somewhat similar fault was discussed before the Society,[1] but in that case the spots were clearly free alkali. It is possible that this is only another stage in the same disease.

2. From my experience I should say that the trouble is met with in most tile works producing majolica, and is generally ascribed as due to "easy fire." It is found usually on tiles drawn from certain parts of the muffle, such as the bottom and back, which do not "come up" well.

3. The cause of a fault such as this may be looked for both in the composition of the glaze and in the way the tiles are fired. As I have had no particulars given to me, for instance, as to whether the trouble is confined to this green glaze or appears on other colours too, I can only suggest several possible explanations:—

(*a*) The glaze may be too rich in alkalies.

(*b*) The glaze may not contain enough silica and boric acid, *i.e.*, its acidity is too low.

(*c*) The frit may not be properly proportioned, and may, in grinding, and subsequently, give up alkalies to the water. In that case the soluble salts would collect on the surface of the dry glaze and during firing aggregate, forming spots.

(*d*) There is obviously a fairly high content of copper oxide and iron oxide, with perhaps some MnO_2 present. This, combined with the high basicity of these soft lead glazes, would assist the separation of alkaline or alkaline earth compounds.

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1 R. H. H. Jones, TRANS., 13, 142, 1913—14.

(*e*) If the glaze is near the danger line in composition these separations will be more likely to occur in kilns or parts of kilns which take longer to bring up to the finishing temperature, and which consequently cool slower. The tile handed to me shows under the glass a network of fine open-mesh lines which I think are the remains of cracks formed in the dry glaze in the earliest stage of the firing. In the absence of fuller information the presence of these lines and of very small pinholes on the surface (not visible to the naked eye), show, I think, that the glaze has not been fully matured.

(*f*) The fault may also be aggravated by not thoroughly drying the tiles after dipping.

(*g*) Another point to which attention might be given is the use of clean water in grinding and in thinning down the glaze. It is possible that some soluble lime and alkalies may have been introduced by the water.

(*h*) I have never seen this fault on thinly dipped glazes, the reason being perhaps that the silica dissolved from the body would combine with any free alkali in the lower layers of glaze. In these majolica goods the glaze is too thick and the time of firing too short for the dissolved body constituents to operate.

Summing up the suggested cures:—

1. Reduce the alkali in the glaze; replacing it with boric acid if it is desired not to harden the glaze at all.

2. Increase the proportion of frit by incorporating with it some of the raw materials such as flint, stone and china clay.

3. Do not grind the glaze for a longer time than is just necessary to enable it to pass through the lawn.

4. Look to the construction and state of repair of the flues in the kiln or parts of kilns from which the defective tiles were drawn.

5. Do not pack the kiln too tightly in the parts known to be slow in coming up.

6. See that the fireman raises the heat steadily and uniformly.

Question:—What is the cause of the Dryness of the Glaze inside the Earthenware Jug? (Sample submitted.)

Opened by F. TURNER.

The question which I have been asked to introduce has reference to a jug, which, while fully glazed outside, is almost bare on the inside surface.

This fault, so far as I know, belongs exclusively to articles made from alkaline casting slip and is, I think, due to a concentration of the alkali on the inside surface, and any manufacturing condition which will assist this should, of course, be avoided as far as possible. One peculiarity of the fault is, that in my experience it confines itself to articles of a similar shape to jugs, that is, with a fairly confined inside surface, and avoids those pieces which have a more exposed open surface such as coverdishes, and also those which are double cast, or without *any* open drying surface.

Several factors, I think, contribute to the fault. *First*, the composition of the slip. I do not think it advisable to add more alkali to the clay than is necessary to produce slip which will flow readily and stiffen in a reasonable time in the moulds. Too much alkali, especially sodium silicate, certainly entails greater risk of glazing difficulties. At the same time sufficient must be added to enable the clay to harden without staying in the moulds too long after they have been emptied. A protracted time in the moulds after emptying away the slip, with a soft pasty condition of the clay, is undesirable.

Second, the drying of the article. All risk of sweating or steaming should be avoided, this causes a concentration of the alkalies on the exposed surface. It will be noticed that in those articles which are more open and can dry more regularly and naturally the fault is practically absent. The condition of the moulds is not a negligible factor. For instance, a perfectly dry mould usually gives a soft pasty condition of the inside surface after the slip has been emptied and is not a good drying mould for articles of this kind. I expect this is due to slip being converted into clay almost immediately on touching the dry mould and leaving it too soon, with the consequence that after emptying practically all the water has to escape from the inside surface. Moulds which are saturated produce the same result. Those which are slightly damp dry quicker and more regularly.

Third, the biscuit firing. While a hard biscuit in my opinion does not produce the fault it certainly makes it more apparent if it is present. With an easy fire the inside surface may be sufficiently porous to take a coating of glaze, although denser than the outside surface.

During a rapid fire, however. especially in the early stages, those conditions of sweating or steaming are produced which bring the alkalies to the surface more readily. The fault is much more likely to be present when a biscuit oven is fired in this way then when the firing is steadier.

Careful attention to these three points will minimise the risk of glazing difficulties of this description.

Mr. BERNARD MOORE:—It may be well to make it quite clear that the fault can be produced by casting in a damp mould and leaving for an undue length of time in the mould. The cast piece dries to the inside, and alkali is deposited there.

Mr. A. G. RICHARDSON:—Bad drying in the shops produces the fault, which does not appear in articles cast from double moulds, even when fired along with ware cast in open moulds. The same kind of action can take place more rapidly in the oven during "sweating," moisture passing off freely from the outside of the jug. I have known parts of the same stock to be set in two different ovens, and one lot came out good and the other lot bad, which suggests that the fault has more to do with firing than with making.

THE PRESIDENT (Mr. A. Leese):—I think the particles are closer together on the inside than on the outside. Drying takes place more slowly in the moulds and the pores on the inside get closed up.

Mr. A. G. RICHARDSON:—I disagree with the President, because articles made in a screw press take glaze well.

Mr. W. EMERY:—I notice that the top edge of the jug, which was fettled, and the bottom of the inside, as well as the top of the handle, are better glazed than most of the inside. The fault comes very badly on ware fired in green saggars.

Mr. F. TURNER:—It sometimes happens that even in the same saggar some pieces are faulty and some good. As regards the bottom of the inside being better glazed, it is probable that the glaze runs to the bottom when melted.

Mr. KIRKLAND:—A batch of 40 jugs was sent into the glost oven, and on being drawn more than 20 of them were dry inside. In order to avoid the possible influence of dry moulds the moulds were kept in the potters' shops away from heat, but the results were just the same.

Mr. B. J. ALLEN:—It is sometimes possible to mark cast ware from the potter, ready to go to the stove, so as to predict places which will not take glaze. There is a sort of wreathing, indicating a patch which will not take glaze, the article being cast thinner at such places.

Mr. F. TURNER:—The fault referred to by the last speaker is flashing rather than wreathing. It is due to greater density of the clay where it strikes the mould.

Mr. A. G. RICHARDSON:—It has often happened that one oven following another is different, good or bad as the case may be. Sometimes early conditions could be traced as faulty.

Question:—What is the cause of the Bowing of Tiles?

Opened by T. A. SIMPSON.

The bowed tile shown to me may be due to a variety of causes, but in my opinion the chief trouble in making this class of tile is:

1. The fact that thin tiles are more liable to go crooked than the ordinary thicker ones.

2. If the tiles are not placed on perfectly straight setters the tiles are bound to follow more or less the shape of the setters, although some manufacturers use no setters at all.

These two facts to my mind are the main source of the trouble. As a minor fault the body may want reducing in the amount of ball clay used.

Mr. BERNARD MOORE:—If they are not satisfactory in the biscuit state, certain glazes will bow the tiles, though thin ones will become bowed more easily than thick ones.

Mr. HARRINGTON:—The effect seems to me to be due to the composition of the body, for if the ball clay and china clay are balanced the bowing effect is less. With a particular body mixture the tiles bowed even with a soft majolica glaze.

Mr. A. J. VAUGHAN:—Tiles set 18 high in a biscuit oven, fired at bar 25 (as in this case), may not get sufficient heat as compared with a glost firing to bar 21, where they are of course not piled up. Possibly if they were set only six high they might come out better in the glost.

Question:—Can Bone China Body be treated in a similar way to Earthenware so that the Slip, while retaining its Fluidity, can be Increased in Weight?

Opened by A. HEATH.

As I only had the question handed to me yesterday I have not had time to make any very exact determination, but I thought the best way of answering it was to show you actual slip experimented on.

I went to a manufacturer's and got some slip just as being used by the caster untreated. This slip was, I considered, fairly thick, and it weighed 27¼ ozs. to pint. I show you a slip treated with silicate of soda. This weighs 35·2 ozs. to pint, and I think you will see its fluidity is all that could be desired.

This other specimen slip is treated with a mixture of silicate of soda and soda ash, and although not so fluid as the previous one the weight is not so high, being only 32·5 ozs. to the pint.

A general impression has, I think, been held that this alkaline reaction would not operate with china body. Some time ago some work was done by two students on the subject and they came to the conclusion that it would not act. After one of our meetings Mr. Allen was talking to me on the subject and said he was sure it would act because he had tried it. Last session I got one of the students to make some trials and the results were quite satisfactory.

I was talking to a manufacturer yesterday and he said if he came to the meeting he should flatly contradict me if I said it could be done. Now I know the only trial this man made was a very rough one in a tub, and a wooden board was used as a paddle to blunge it up.

I have been told that the process has been in use at one works for some years, and one manufacturer intimated to me that in his opinion such fact was known at the Pottery School and that the information was withheld for that special manufacturer's benefit. I think anyone here knows that such is not the case. But on looking through the TRANSACTIONS I find the question has never been asked, so I am pleased it has been raised, as manufacturers will now know that the china body can be so treated and it is up to them to put it to practical use. I might say that I think the cause of failure by the two students referred to was that they took the proportions used for earthenware body to be the minimum amount, whereas if they had started with that amount as a maximum their results would have been different.

I should not like to give actual figures as the trials before you have been so hurried, and naturally different bodies would behave differently, but I think it is quite clear that the process can be successfully used.

Since giving these notes I have spoken to another manufacturer and he tells me he is using the process satisfactorily on a small scale.

Mr. B. J. ALLEN :—I have made china slip which weighed 38 ozs. to the pint.

Question:—What is the cause of Blebs in Earthenware made from Alkaline Casting Slip?

Opened by A. G. RICHARDSON.

The presence of such blebs as are complained of and as seen in sample pieces shown may be due to various causes.

I venture to suggest several possible causes:—

1. To use of clay or scraps which are too dry, and to insufficient blunging which does not allow sufficient time to expel the air contained in the pores of the dry clay.

2. Insufficient blunging when plastic clay is used, air introduced by rough method of charging not being expelled.

3. The use of alkalies, soda ash and silicate of soda in such quantity or ratio as will render the slip viscous instead of fluid, and in such viscous condition prevents the escape of air bubbles.

4. Feeding the moulds with slip under too great a pressure when fed by taps or when fed by hand by pouring the slip in the mould too quickly or too rough.

5. If the slip is used by the worker direct from tubs—rough agitation of the slip in the tub is a prolific source of blebs.

6. The surge of the pump, or a badly-packed pump. When pumping the slip from the stock ark to the shops either to feed a stock tank or to be used direct from taps is also a common source of blebs.

7. The use of moulds too wet or too dry.

Also after the slip has been prepared on the blunger all subsequent treatment of it should be such that avoids extreme agitation, gentle but constant movement giving the best results.

If the slip is exposed to air it becomes thick or viscous, and if when stirred any air is introduced it is difficult to get rid of it owing to its viscous condition.

These are some of the causes of blebs in earthenware even when funnels are used.

The use of funnels is more effective in preventing marked and dense surfaces which are caused when the slip falls direct on the face of the mould rather than preventing the formation of blebs, but the use of funnels when the slip is allowed to fall on the side of the funnel certainly does reduce the possibility of blebs.

THE PRESIDENT (Mr. A. Leese):—The thickness of the sample piece suggests the use of thick slip. The proportion of scraps used in making casting slip is a point to be considered.

Dr. MELLOR :—It is well to bear in mind the possible effect of organic matter in the ball clay present in the slip. The decomposition of this organic matter is sometimes completed in the blunger, and bubbles of gas may be produced.

Question :—The percentage of Spit Out has increased since we started to use 50 per cent. Ground Glost Pitchers in place of the Stone formerly used in making the glaze. What is the cause?

Mr. BERNARD MOORE :—This question has been given to me to answer, but it is too indefinite to enable me to deal with it satisfactorily.

Mr. A. HEATH :—If it is right to assume that the glost pitchers were substituted for stone weight for weight, the change would harden the glaze considerably, and this would be likely to help in causing a certain kind of spit out. Judging from the results described in Mr. Emery's recent paper on the substitution of pitchers for stone, the amount of lead present in the glost pitchers would not materially soften the mixture.

Mr. F. S. WORTHINGTON :—In using glost pitchers instead of stone, as indicated in the question, it was found that the glaze set much more quickly, and it was much harder for the dippers to dip the ware properly. There seemed to be more spit out ware, but the glaze had a much better colour (whiter) and was, of course, decidedly cheaper.

LANCE-CORPORAL GILBERT E. MEIR.

AMONG the war's victims in our Society, Gilbert E. Meir will not be missed least by those who knew him well. He had been wounded in the attack on the Hohenzollern Redoubt, 13th October, 1915. He died on the 1st July, 1916, at the age of 24, in the charge at Gommecourt, having only a short time previously been recommended for a commission.

Second-Lieut. Reginald Tivey, at that time a Corporal, was the next man to Meir, and saw him fall. In a letter dater October 22nd, 1917, Second-Lieut. Tivey wrote: "I have known Gilbert very intimately since the commencement of our military career, having been in the same Battalion, Companies and Platoons right up to the fateful day in July, 1916. There is nothing I can write which can adequately express my admiration for him both as a 'soldier' and a 'man' in

the highest senses of the words. As a soldier he was fearless and cool to a degree, entirely reliable, and possessed an intense regard for the meaning of the word 'duty.' Some days before the charge, when out with a working party between the lines, some numerous casualties obtained in his platoon. The man next to him was seriously wounded and appealed for assistance. Gil remained with him during the short yet severe 'barrage,' and ultimately assisted him into the trench. This action is difficult to appreciate fully, but to those who know the nature of the ground, its pitfalls, and the apparently hopeless desolation of 'No man's land,' an action of such nature is, at least, in keeping with our traditions. That the wounded man died in the care of his comrades was solely due to an unselfish action. Characteristic of Gilbert, he never spoke of this."

Gilbert Meir's early education was acquired at the Leek High School, and when 17 he commenced to study at the Stoke-on-Trent Pottery School under Dr. Mellor. At the end of the second year he gained the Bronze Medal for the Ordinary Grade (1911), followed the next year by the Silver Medal for the Honours Grade, and later secured Mr. Ashley Myott's Special Prize for research in 1913.

What The Ceramic Society lost through Gilbert Meir's untimely death will probably never be known. He gave up useful work to do his duty to his country. Though nothing from him has been published in the Society's TRANSACTIONS, he had done a considerable amount of work on "Iron Reds," and his notes on this work are in hand. Probably the results will eventually appear in a posthumous paper in the TRANSACTIONS.

The following brief extracts from a letter written by the principal of Stoke-on-Trent Pottery School will serve to show the estimation in which Gilbert Meir was held: "His was a fine noble character, and he was universally respected by all his colleagues. We feel his death most keenly, he was one of the most promising men we had for the coming generation." . . . . . "Losses of men like Gilbert are permanent, and can never be made good. He was an asset to the district and to the nation. It is to Gilbert's credit that he saw the need for combating the German menace from the very first."

One of his fellow-workers at Stoke wrote: "I don't think anybody ever said a word against him, he was so straightforward and honourable in everything he did. This modesty and quietness rather obscured his other gifts until one knew him. It was not a bit surprising that he joined the army at the beginning." . . . . . "I'm certain that everybody who worked with him at Stoke will never forget him."

J. A. A.

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ERRATUM.

ge 383. Fourth line of Analysis, for "F_2O_3"
read "Fe_2O_3"

ge 384. Second line of Analysis, for "Copper as [?]"
read "Copper as CuO"

ge 505. In Fig. 1, for "Ferric oxide F_2O_3"
read "Ferric oxide Fe_2O_3"

XIX.—On Hydraulic Separation as Applied to the Recovery of Fine Coals, Shales, and Clays.

By John M. Draper.

I am sensible of the honour conferred in your invitation to read a paper on Hydraulic Separation before the members of The Ceramic Society. But I fear I shall be able to offer you little more than a short experience of a newly-designed apparatus for this purpose—an experience so far chiefly confined to the recovery of extremely fine coals by separating them from their accompanying shales. By fine coals I mean those capable of remaining on a standard 100 mesh screen, equal, I believe, to what you term 100's lawn.

It is not intended to convey the impression that 100 mesh is the limit of satisfactory separation. It is not, except in an economic sense. Below 100 mesh dewatering of coal becomes difficult and the apparatus frail.

Neither do I desire to claim for my apparatus that it solves all problems of clay purification.

The problems of coal and clay are manifestly different, chiefly owing to the extremely fine particles of clay substance and its colloidal character—moreover, dewatering difficulties are enormously greater. All I can hope is that, from a study of the simple apparatus I shall describe, we may be able to extract a few grains of useful knowledge, and thereby gain a step toward economic progress.

Our coal friends have necessarily had to consider coal washing, or purification, much earlier than those of you whose interests lie in clay.

By hydraulic separation we mean broadly the separation of mineral particles, by taking advantage of the different velocities of fall of equal-sized grains, but unequal specific gravities, in water.

All washing and hydraulic systems depend on this principle for success. Applied to coal the natural evolution of the apparatus passes from the long trough (somewhat like the Devon and Cornish method of clay purification), through various types of increasing complexity to the modern pulsator or jigger,

where the raw material is treated in water agitated by a plunger from a separate compartment, producing an upward current through the raw material, and floating the lighter portions over and outward into a suitable collector.

Now down to $\frac{1}{8}$ in., or slightly less, there is very little difficulty in making good separations. Below this size the difficulty increases, until it is common practice to screen out all coal below $\frac{1}{8}$ in. or more and deal with it dry.

Even in the most modern machines defects due to wear and tear constantly add to the factor of lessening efficiency, and in no case is more than a small portion of the coal product below $\frac{1}{8}$ in. recovered. It is with these "fines" we have to deal with at the moment.

It may be asked how we account for the difficulty in dealing with fine sizes in modern machines. First we have the fact of the extremely low falling velocity of the fine particles. This means that fine coals and shales remained suspended in the washing water and do not settle out within the limits of economic time. Second, we have the problem increased by the greater surface of fine particles exposed, in relation to size and specific gravity. Third, we have the retardation of fall due to colloidal clay, and similar substances in the washing water, apart altogether from the numerous and extremely interesting problems connected with the size, shape and porosity of the material.

In point of fact extremely fine materials do not quite satisfactorily conform to the law of equal falling bodies for reasons I have in part just stated. More especially is this emphasized in jigger or plunger machines with reciprocating pulsators which exert a suction effect on the return stroke. Fine coal losses from these machines will range from 2 per cent. to as high as 20 per cent. or even more in older or inefficient machines.

As to the tonnage of fine coal in this country no reliable figures are available, but a conservative estimate will indicate possibly four to five million tons per annum. The recovery of this coal, therefore, becomes one of urgent national importance.

Many attempts to recover these fine coals have been made, chiefly in the type of apparatus known as the hydraulic classifyer, used in ore dressing mills for extracting sands from slimes. These have more or less followed the lines of the well-known "spitzkasten" or "spitzlute," or "pointed box," consisting of an inverted pyramidal form with a hydraulic inlet connected with the water supply and operating with an upward water current, causing the finer slimes to flow away from the coarser sands. These failed for various reasons, chief of which

was the volume of water required, the difficulty of evenly feeding and discharging the device and the attention required.

Hydraulic separation, to be practicable, must follow certain simple but very definite laws, based upon a definite relationship between size and shape of grains and relative specific gravities.

To restate in simple terms the law of equal falling bodies in liquid media, it is known that if we cause two pieces of mineral—say coal and shale—to fall at the same moment of time in a deep vessel of water, the dimensions of both coal and shale being equal, the shale being relatively heavier, will reach the bottom first; but if the coal is much larger the velocity of fall would be equal.

Rittinger long since gave us an equation for ascertaining the velocity of fall according to the size and relative specific gravity, which with comparatively little modification stands to-day, at least so far as the larger cubes of material are concerned. It follows, of course, that if we know the velocity of fall of any given size of cube we can also ascertain the velocity of water required to keep the material suspended, or with equal size grains can cause the lighter portion to flow upward and away from the heavier.

Based upon the experiments of Rittinger and others we have the equation:—

$$V = C\sqrt{D(S-1)}.$$

where V = velocity in feet per second.

C = a coefficient, which for clean water is 1·28.

S = specific gravity of the particle.

D = diameter of cube or size of grain.

From what has been said in reference to the law of equal falling bodies it will be obvious that the most perfect sizing of grains is necessary before we attempt separations.

I would like now to describe a recent modification in hydraulic separators specially constructed to deal with the finer sizes.

This apparatus has been designed to give effect to certain conditions considered essential in dealing with fine materials.

These conditions may partly be summarized as follows:—

(1) Finely-sized grains should be allowed to fall a short distance only before separation is effected.

(NOTE.—Grains of high specific gravity fall more rapidly during the early part of their fall in water than grains of lower specific gravity, although in time they would otherwise attain a similar velocity.)

(2) Impulsive or artificial velocity of grains due to unequal feeding rate should be gradually reduced to normal velocity by the creation of a zone of constant maximum effect of uprising water.

(3) After separation, the heavy grains should fall into a collector of still water as free as possible from eddying or eccentric currents, and their removal be effected without disturbance to the upper separating zone.

(4) As a perfectly even rate of feeding is not practicable, disturbances due to this cause should be neutralized somewhat in the manner as will be described.

Description (Fig. 1).—1, is a tubular body entirely filled with water; 2, a feed inlet, and 3, a discharge outlet; 5, is the hydraulic inlet connected to supply tank, and 15, a cone with suitable perforations and an elongated portion of a parallel-sided tube extending downward and flared outward at the lower end; 7, is a connection to the compensating head, as will be described; 23, is a sampling valve; 22, inspection windows; 26, a rotary valve for discharge of heavy product into the screw conveyor, 13.

The operation is as follows:—A valve in supply pipe to inlet 5 is opened and a strong current is passed until a flow is established over the cill 3.

Leaving out of consideration the second opening 7 for the moment, the feed of fine coal or other material to be separated is started. The descending materials enter the internal cone, meeting the uprising water until they are arrested in the case of the lighter grains, and eventually are carried upward and outwards with the water current. The heavier grains find their descending velocity gradually diminished until they reach the downward extension at the bottom of the cone, where maximum velocity of water effect is secured. Into this zone the heavies for the present cannot penetrate, so they gradually accumulate in the lower portion of the cone. The hydraulic water flow is gradually diminished until the heavy grains only can descend, as will be seen from the inspection windows provided. In other words, just sufficient water velocity is maintained in the tubular portion of the cone to allow the heavies to penetrate, while the lighter grains return and go over.

The discharge of the coal over 100 mesh draining chutes, and the shale into a screw conveyor and outward by way of a suitable elevating device scarcely needs detailed explanation.

We have left out of consideraton a description of the connection to outlet No. 7. This flanged portion is coupled

to a long tubular extension ending in a closed end fitted with an air valve. The tube is sufficiently long to allow about one foot of air space over the normal water level—maintained

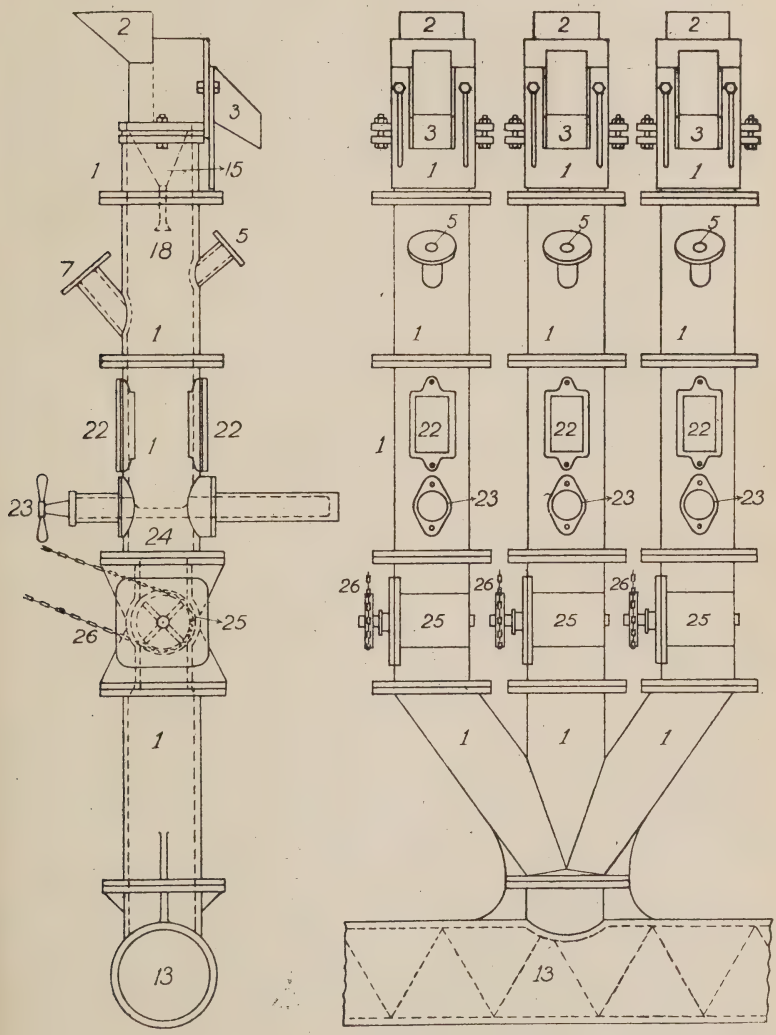

Fig. 1.

while the apparatus is in operation with the air valve closed. Recalling what was said about the impracticability of securing

a perfectly even rate of feeding, this device provides a compensating balance, instantly acting and reacting through the water, and maintaining a constant effect in the separating zone.

It will be obvious that this design gives us a ready means of obtaining the conditions of almost perfect separation. We have a fixed water head which means a fixed velocity of uprising water, but variable to the slightest degree by the control valve. We have a zone of maximum effect in the central tube leading to the cone. Into this zone no particle can penetrate except the one whose velocity of gravitational fall is greater than the velocity of the uprising water. This means that no particle of heavier material can float over the lighter grains, provided its size is equal or nearly so.

Perhaps you will like to ask how close will this apparatus separate grains having specific gravities nearly equal, in other words, how narrow may the margin be. As an experiment to demonstrate this I had a mixture made of equal weights of bituminous and steam coals having a carefully taken specific gravity of 1·27 and 1·33 respectively. The actual size of grain was $\frac{1}{16}$ in., and the mixture was passed through the separator with a current velocity of about ·38 ft., equal to say $4\frac{1}{2}$ in. per second.

The separator delivered 56 per cent. of the mixture with a specific gravity of 1·28 and 44 per cent. with a gravity of 1·32. As the margin between the specific gravities of the two coals was only ·06 to begin with, it will readily be seen that the apparatus can be worked with considerable exactitude. The difference between coal and shale or clay is generally at least ·8 to 1·0.

The process has been applied to the recovery of slurry and waste from other washers, the retreatment of ground bastard coals, picking belt waste and such unlikely material as fan drift and underground and overhead road cleanings. At one colliery a plant on this principle is delivering some 1,500 tons per month of pure fine coal into by-product coke ovens, giving a superior coke of 7·5 per cent. total ash, made from slurry containing mixed coals averaging a total ash of 25 per cent. to 27 per cent. before treatment. The fixed ash in this coal is over 5 per cent., hence the washed coal is delivered to the ovens in all sizes from $\frac{3}{16}$ in. down to 100 mesh within about 1 per cent. of the fixed ash.

An interesting feature due to the entire absence of clay and shale is the perfect drainage. It has been found that in four hours the washed fuel will drain in wagons down to 8 per cent. moisture, a remarkable result when it is known that at

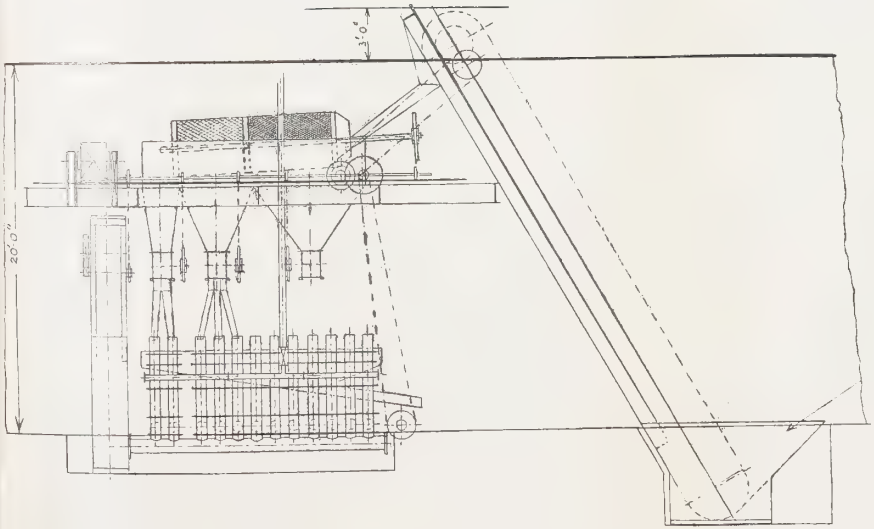

Fig. 2

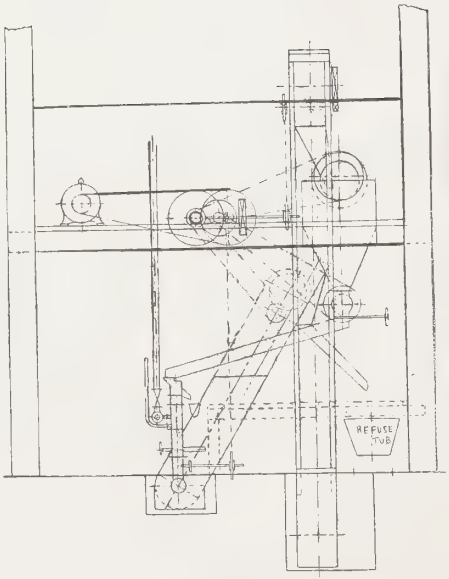

Fig. 3.

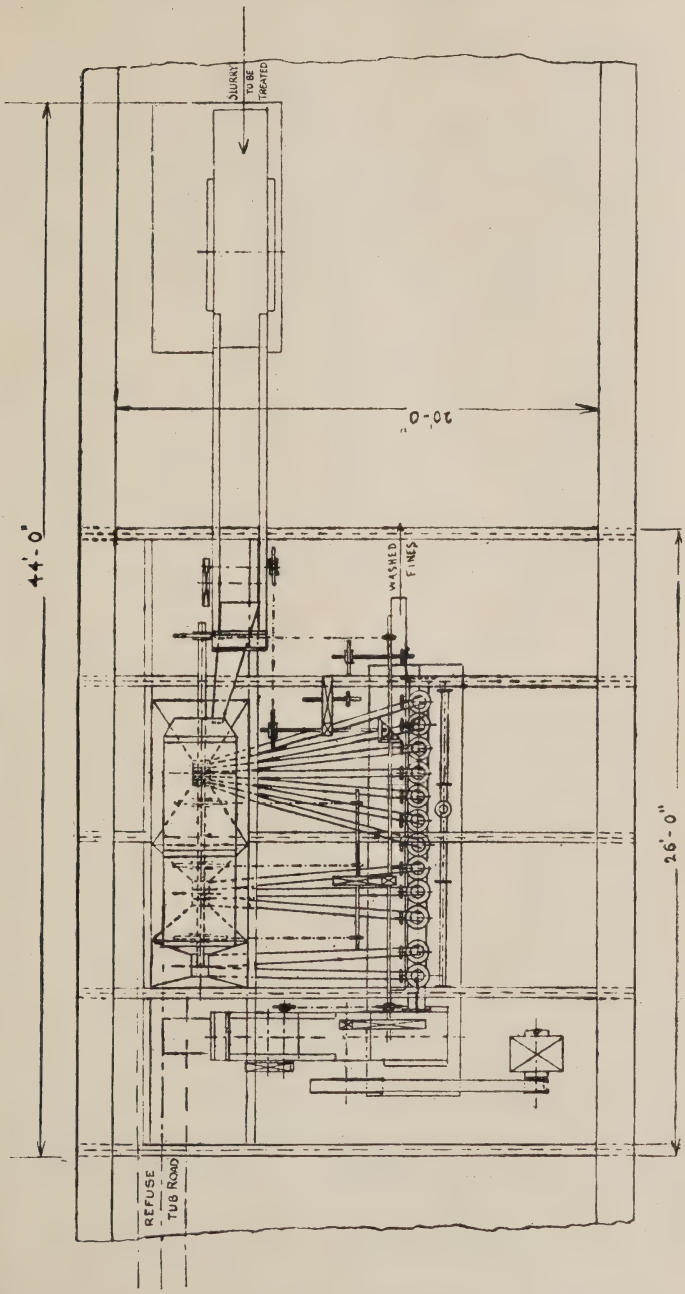
SLURRY TO BE TREATED
20'-0"
44'-0"
WASHED FINES
26'-0"
REFUSE TUB ROAD

Fig. 4.

least 20 per cent. of the fuel will pass an 80 and remain on a No. 100 standard brass wire mesh screen.

Thus we are able to deal with the finer sizes of coal and shales, but the process has the further advantage—the shales removed are quite free of coal. The fireclay shales of the coal measures become available for brickmaking. Recently 100 tons of a steam coal rubbish tip in the Rhondda Valley was passed through this separator, resulting in the recovery of 20 per cent. of coking fuel and 80 per cent. brick shale, which latter gave a good class brick for building purposes.

Again, a Derbyshire coal was separated into:

70 per cent. clean coal of 4 per cent. ash.

15 per cent. brick shale.

10 per cent. clunch or fireclay.

Can this process be used for, or assist in the purification of clay or marls?

If I understand the problem of clay purification rightly you require a process to reduce free silica, remove coal, pyrites, mica, certain iron minerals, alkalies, and other substances easily and economically while keeping the clay substance in a colloidal condition.

With a perfectly controlled current velocity it is easy to see that many of the above impurities are removable, and that clay slips passed into the separator, exposed to a sufficiently low velocity to suit the particles of clay substance contained, must lose a considerable portion of their heavier impurities.

It is recognised that colloidal clay presents one of the most difficult problems in separation, but I think I can claim for the apparatus I have just described an exceedingly simple instrument, which even in unskilled hands can be made to fulfil all the conditions laid down previously for the sizing and separation of fine particles, and I may further claim that clays and marls may be included.

I have not thought it necessary to describe the several "elutriators" known to the clay industry, as I feel sure that they are familiar to you all. In no case do they appear to be other than instruments for laboratory testing, and owing to limitations in design cannot enter into the field of practical operations necessary to the clay worker in the field. Probably the want of a successful separator or elutriator for clays and allied products that is capable to continuous and automatic service in even unskilled hands is the chief reason we in Great Britain, with our magnificent variety of clays, have not done more in clay purification than we have done in the past.

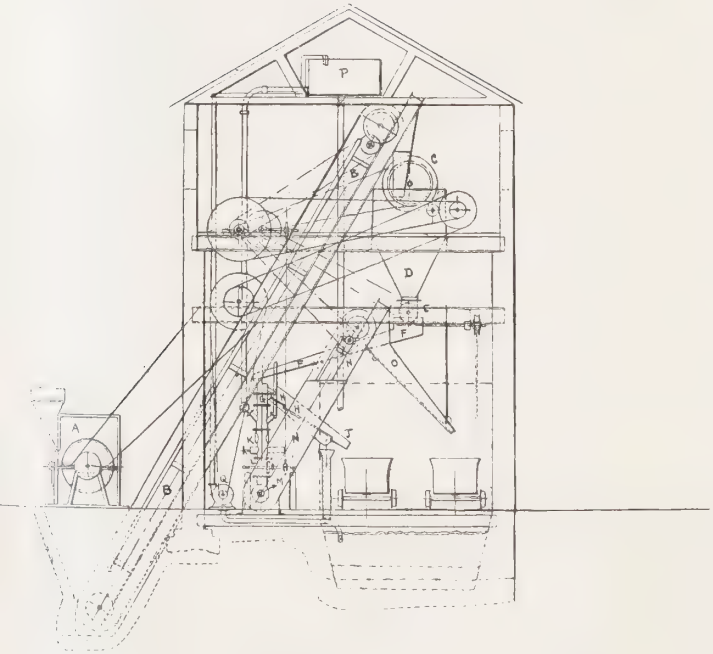

Fig. 5.

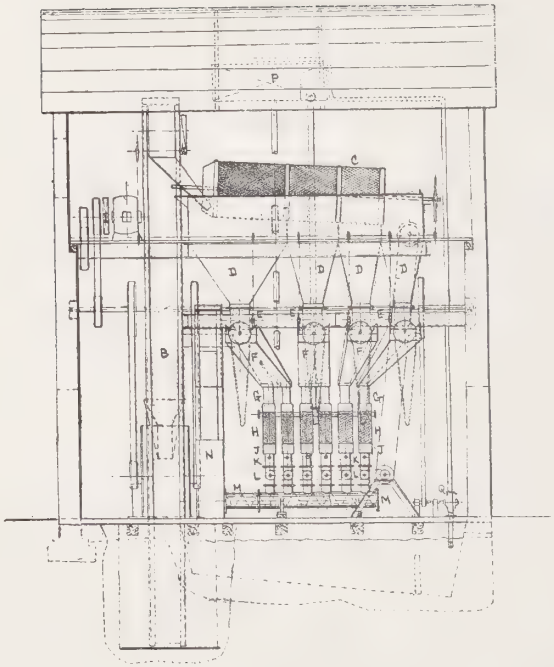

Fig. 6.

TABLE OF PRACTICAL RESULTS.

No.	Initial	Material	Ash Before Treatment	Ash After Treatment	Ash of Shale Recovered
5	B. Coll. Co., Ltd.	Fine Coal	31·00%	5·7%	71·25%
11	M. H. Coll. Co.	,,	22·72%	4·1%	73·28%
12	Cap. Coll. Co.	Slurry, ⅛" to 0"	23·70%	7·2%	70·60%
13	M. Main Coll. Co.	,, 1/25" to 0"	13·28%	4·25%	67·45%
15	,, ,,	Belt Pickings crushed	35·80%	8·60%	71·75%
17	F. Coll. Co.	Slurry	30·25%	4·83%	74·02%
18	,, ,,	Slurry	18·42%	5·21%	70·10%
19	,, ,,	Slurry	16·00%	5·03%	62·90%
26	Cl. Colls.	Anthracite Shales and Rubbish	49·07%	5·46%	81·04%
31	M. & Co., L'pool	Waste Slack	24·95%	11·12%	62·10%
41	C. C. Co., Ltd.	Fine Coal	18·42%	3·75%	66·80%

(1) Welsh Fire Clay Sample.

A Raw Clay.
B Recovered Clay Substance, 30%.
B2 ,, ,,
B3 ,, ,,
C4 Shale from above Sample, 70%.

(2) Sample of Staffordshire Waste Clay.

ROM. 1 Clay
2 ,, } 50%.
3 ,,
4 Shale Separated, 50%.

Mr. W. SIMON:—I have much pleasure in proposing a vote of thanks to Mr. Draper for his very interesting paper.

His method of washing seems to have solved the difficulty so far as fine coal is concerned, and will undoubtedly be a means of using very large quantities of fuel that have up to the present been very difficult to deal with and in many cases have been thrown away.

Economy in fuel is of the greatest importance, and those who have read the report of the committee appointed to investigate this matter will clearly see that it will be necessary to do everything possible to economise, and a great deal of fuel will be saved and will go far to help to provide the money that the industries of this country will no doubt have to contribute towards the enormous cost incurred by this war.

It seems to me that Mr. Draper's washer deals with two difficulties we have had to face. The first is the sludge obtained from the washer. This sludge is extremely fine and contains 20 to 30 per cent. ash and for years has been a "bugbear" to

the coal owners. Owing to the high ash content it was not in many cases desirable to put it back with the washed fuel as it deteriorated the quality of the coke, and again, owing to its very fine nature and ash content, it was not suitable to use under boilers, even though special grates were adopted which claimed to be able to deal with this quality of fuel.

The result is that no doubt thousands of tons of this material have been wasted, but the washer put before us by Mr. Draper will enable a large quantity of this to be separated and utilised to advantage.

The other difficulty that would be overcome is the dealing with the interstratified fuel, *i.e.*, the dirty fuel with interstratified flakes of coal which is at the present thrown away. In this case a crusher would be necessary and the fuel now thrown away could be saved.

There is a very large field for the washer placed before us this evening, the paper has been very interesting, and I have very much pleasure in moving a vote of thanks to Mr. Draper.

Dr. J. W. MELLOR:—I have much pleasure in seconding the vote of thanks to Mr. Draper. Mr. Draper has described the essential principles of his process very clearly. Although the process has been very successful with coal it has not yet been tried with clays, and our Society is of course more interested in clays. I thought it well to try and persuade Mr. Draper to develop his process on the clay side since it looks promising. Of course no one can tell what it will do until it has been tried. Let us see just what part it could play in the work in question.

The purification of clays involves two main operations:—

1. The "slipping" of the clay and removal of impurities:

(*a*) By sedimentation, analogous to a process used locally and called "washing up." The settling of the impurities may be facilitated by the addition of small quantities of electrolytes which keep the clay in suspension and allows some of the non-clay impurities to settle.

(*b*) By lawning the slipped clay. This is not so good as sedimentation, but it may suffice except in special cases.

(*c*) Possibly by a modification of Draper's process.

2. The removal of the water from the purified clay. There are quite a number of methods available for de-slipping.

(*a*) By settling pits and kiln such as is used on the china clay works, maybe accelerating the settling by the addition of a trace of alum or acid.

(*b*) By filter press, as used at West of England works, and in scores of works in the district.

(*c*) By Gee's centrifugal process as used at china clay works near Roche.

(*d*) By slip kiln, as was formerly used extensively in this district.

(*e*) By electrical precipitation as used by osmose process.

The particular virtue of the German "osmose" process seems to me to lie, not in the particular means by which the washing and the subsequent removal of the water are effected, but rather in the washing itself. A great many of the virtues claimed by the osmose process could be also claimed by any system of washing. Some impurities which the osmose process claims to remove need not be removed at all. The reversal of colloidal silica from electro-negative to the electro-positive state which occurs in $\frac{1}{2}$ to $^1/_{10}$ N. solutions of hydrochloric acid, shown by Billitzer (1905), enables a practical separation of silica from colloidal clay to be made. This is a most important point, but whether it is industrially important remains to be proved, although Schwerin has patented applications of the general principle. The china clay refiner, for example, might reasonably ask: Why remove the finest quartz from china clay? The free silica is put back again when the clays are used in pottery. The electrical precipitation may or may not be cheaper than the other methods; if it turned out to be cheaper, and Draper's process of washing proved to be efficient and cheap, it might be practicable to combine it with electrical precipitation.

Mr. B. J. ALLEN:—There is one question I should like to raise. Mr. Draper said that the hydraulic apparatus would separate colloidal clay. I was astonished to hear this and should like to know what is the smallest size of particle which can be separated by the process described, and the rate of separation of such particles.

With reference to Dr. Mellor's remarks, I am not in agreement that electricity does not play some part in the purification of clay.

The addition of electrolytes to clay suspensions can produce and augment Brownian movements, and by the use of suitable electrolytes the different suspended particles can receive electrical charges which play an important part in the final result.

The separation of colloidal particles of clay from certain other colloidal materials suspended in water can be brought about electrolytically, and as far as I am aware cannot be done by any other process.

The precipitation of colloidal clays by the addition of aluminium sulphate or other alum salts does not give the same results and, further, the plasticity of the finished material is considerably less.

The use of a suitable electrolyte and the electrolytic treatment of clay play an important part in the purification obtained.

Patent specification No. 14369 of 1912 (page 2, lines 9-11) claims the separating of adsorbed colloidal ferric hydroxide from clay by *electro*-osmosis.

Patent specification No. 24666, 1912, describes the methods of separating from mixtures of suspensions a particular substance of a particular size of particle.

It would be interesting to know if these results may be obtained by any other treatment.

Mr. J. M. DRAPER:—It is necessary to suit the velocity of the water to the size of the particles. I am disinclined to say I could take out fine china clay and separate anything more than the coarser particles such as pyrites and mica. Many crystalloids can be got out easily, but not colloids.

Mr. E. M. MYERS:—As far as actual separation of particles of different specific gravity by an upward current of water is concerned the washer described is not new, but it had to be modified for application to fine coals. After separation is accomplished how is the water removed from the cleaned fine coaly matter? The residue on the 100 mesh screen (that is 10,000 mesh per square inch) is practically a mud. How can it be reduced to workable limits? How is slurry screened which contains at least 20 to 30 per cent. of water?

Mr. J. M. DRAPER:—The screening is done by revolving the screen in water. Originally the screen was placed low down and the sized products elevated. This was not satisfactory. I therefore raised the screen and partly submerged it in water. The sized products now pass into separate compartments in the hoppers underneath, where they are passed by way of the distributor valves to the chutes and thence to the tubular separators.

Sizing, as has been shown, is most important, but with this apparatus presents no difficulty.

Dewatering the coal over 100-mesh is not easy, but we are passing over 20 tons per hour over skeleton chutes fitted with 100-mesh with good results.

Mr. E. EVANS:—There is very little that I can add to the discussion on Mr. Draper's paper, but I can perhaps thoroughly confirm his statements as to the efficiency of his washer.

It has solved a problem that has long confronted the coal industry—the treatment of washery slimes.

As a general rule the limit of good washing can only be attained with coal above $^1/_{20}$th of an inch in diameter, and it is the practice with many chemists in determining the clean coal in a sample of colliery small, to eliminate the coal below $^1/_{20}$th inch size as silt that could not be improved by washing.

The Draper washer, however, is successfully treating at Llwynypia, coal down to a size remaining on a 100 mesh sieve, and this size is now the limit of laboratory determinations. Incidentally, a laboratory model of the Draper washer has proved of the utmost service for determinations of the percentage of coal and shale in small coal. It is far simpler and far cleaner than the old method of separating the ingredients in calcium chloride solution or in chloroform.

The question of draining the washed slime has been raised by one of the speakers this evening. This has offered no difficulty at Llwynypia. The coal is simply run into trucks from the washer and in a few hours the moisture content is reduced by drainage alone down to about 8 per cent. The probable explanation is that the coal retains a more or less cubical structure down to the smallest particle than can be washed. The coal "flour" has been removed, together with the shale, and there is nothing therefore to prevent the passage of the water.

Fig. 2 is a diagram of a fine coal recovery plant to deal with 20 tons per hour.

Fig. 3 is an end elevation.

Fig. 4 is a plan of same.

Figs. 5 and 6 show respectively a side and front elevation of a plant to deal with 10 tons of waste from rubbish tips per hour.

XX.—Sudanese Pottery.

By F. STIRK, Omdurman.

Introduction by W. EMERY.

THE paper which I am going to read to-night is the result of a visit paid by Mr. Stirk to this district in July of last year. He came to the "Pottery School" to consult Dr. Mellor on technical points regarding the pottery industry in the Sudan. He had brought with him several pieces of ware, one of which aroused Dr. Mellor's admiration as to what could be done by skilled workmen without the use of mechanical appliances. The particular article I have referred to is now on view, and, after a thorough examination of it, I think you will agree with me in saying that it is a very creditable production. The remarkable lightness, good shape, absence of seams, and the final polished surface all help to make it a first class article, and many potters would be puzzled to say how it had been made without the use of moulds or thrower's wheel. Dr. Mellor asked Mr. Stirk to write a short account of the methods of manufacture, and it speaks well for the Society's reputation when a non-member will go to the trouble and expense of taking photos. and sending them, together with fired specimens, to Stoke, a distance of nearly 5,000 miles.

Whilst Mr. Stirk was staying in the district I had the pleasure of conducting him round several of our local factories, and as a consequence, he had rather an unusual complaint to make: We were too modern in our methods. Usually we are told the opposite, and it came as a pleasant surprise to hear his remarks. Nevertheless, his complaint was made in all seriousness; what he really desired to see was a factory without machinery of any kind, transport difficulties and fuel costs rendering mechanical methods almost useless in the Sudan. I think the greatest difficulty Mr. Stirk encountered in his efforts to introduce other processes was the deep resentment the natives had to any suggested alteration in working methods. I am afraid this is a characteristic not solely confined to Sudanese potters.

In writing a paper on Sudanese pottery it will be sufficient to just notice the different kinds of pottery which have been

discovered in later years, showing influences of Ancient Egypt, Greece and Rome. From the Arab conquest downward the potter's art has been moribund, reverting back to the most primitive household utensils, water cooling vessels, and only in widely scattered places have isolated attempts been made to supply local needs covering a small area.

The towns and villages on the Nile, north of Khartoum, within Sudan territory, with a fairly indigenous population always in touch with Egypt, had a more or less regular supply of pottery which their limited requirements needed. The desert Arabs have no use for pottery vessels; their drinking utensils are made from the gourds which are grown in the country. The itinerant population of the Sudan, and those who are far removed from the lines of transport, constitute the bulk of the population, consequently pottery, or the need of it, has not been felt, except by Europeans and Egyptian settlers in the country.

The pottery made in the Sudan consists mainly of various types of water-holding vessels and cooking utensils. These are made on the banks of the River Nile, or where there is a fairly constant supply of water. The main body of the material used is Nile mud, which in itself is very plastic, but requires the admixture of a binding material, which is supplied by mixing with the body various proportions of camels' or asses' dung. When burned this also gives the porosity required.

The pots are built up from the ground by hand in several layers, each layer, as it is worked into shape, being allowed to dry before another layer is added. The only tool the potter uses is a thin flat piece of iron which assists him in forming the vessel, and keeping a smooth exterior surface. Most of these vessels when finished are carried on the head, and to assist in getting a firm grip when lifting the full vessel from the floor, the exterior surface, when in a soft condition, is pressed into a series of corrugations made by pushing the thumb into the soft clay. These vessels have a capacity of about three gallons, but these pots are now being rapidly superseded by the ubiquitous petroleum tin. Special large sizes are made for brewing and also for tanning and dyeing. The colour of the ware is usually bright red, but in certain localities near Omdurman the pottery made is quite black. This is caused by the method of burning, and by the mixture of dung added to the clay.

The firing is done by placing the dried clayware in a small pit dug in the earth. The fuel is usually dung of animals, which covers the ware, and the articles are slowly baked for

a few hours, producing finished goods which are fairly strong and light in weight.

An article used as a coffee pot, and made in Omdurman, called a "gebbana," is a vessel peculiar to the Sudan. It is made from a red clay found locally rich in hematite. There is no recognised industry, the trade being in the hands of a few individuals scattered up and down the locality, who work in a spasmodic manner. The demand is dependent on the economic conditions of the natives, whose material welfare hinges to a great extent on the rainfall of the year, a good rainy season ensuring cheap corn, and consequently leaving a surplus for the purchase of other necessities, one of which is coffee beans, brought down the White Nile from the Abyssinian town of Gambella. The coffee pot makers confine themselves to the making of their own particular articles, and make none of the other domestic utensils mentioned previously.

The following photos. will probably give some idea of the various stages in the making of a Sudanese coffee pot.

No. 1 shows the initial process in the forming of the base of the pot, which is spherical, and is moulded into shape with a wooden pestle covered with cloth to the exact diameter needed. The potter takes a portion of clay, works it with his hands into a flat cake, which is then patted round the wooden form until the basin-shaped article shown in the photo is formed.

No. 2 shows the upper half being joined to the lower. This is formed similar to the bottom half. The two are joined together in the manner shown, and the potter gently taps the joint with a bent piece of flat iron until the two portions are thoroughly incorporated. The pot is then a complete sphere, with a small hole cut out of the top to take the spout.

No. 3 shows the potter smoothing the irregularities inside with his finger and also preparing the joint for the spout, turning the pot round in his hand while doing this.

Photo No. 4 shows the method of putting on the spout. The potter's stock of clay is in the broken vessel on his left, and the pieces of iron with which he gently taps the vessels in shape are shown on his right. The hole in the spout is worked out with his fingers, and the joint made on to the vessel by moistening round the hole in the top so that the two can be securely fastened together.

No. 5 shows the handle being placed in position. The coffee pot, when finished, is stood upon an annular pad made of cloth, and in use is usually in the position shown on the photo. The pot is now ready for finishing; the ornamentation, generally wave pattern and spiral designs, is incised on

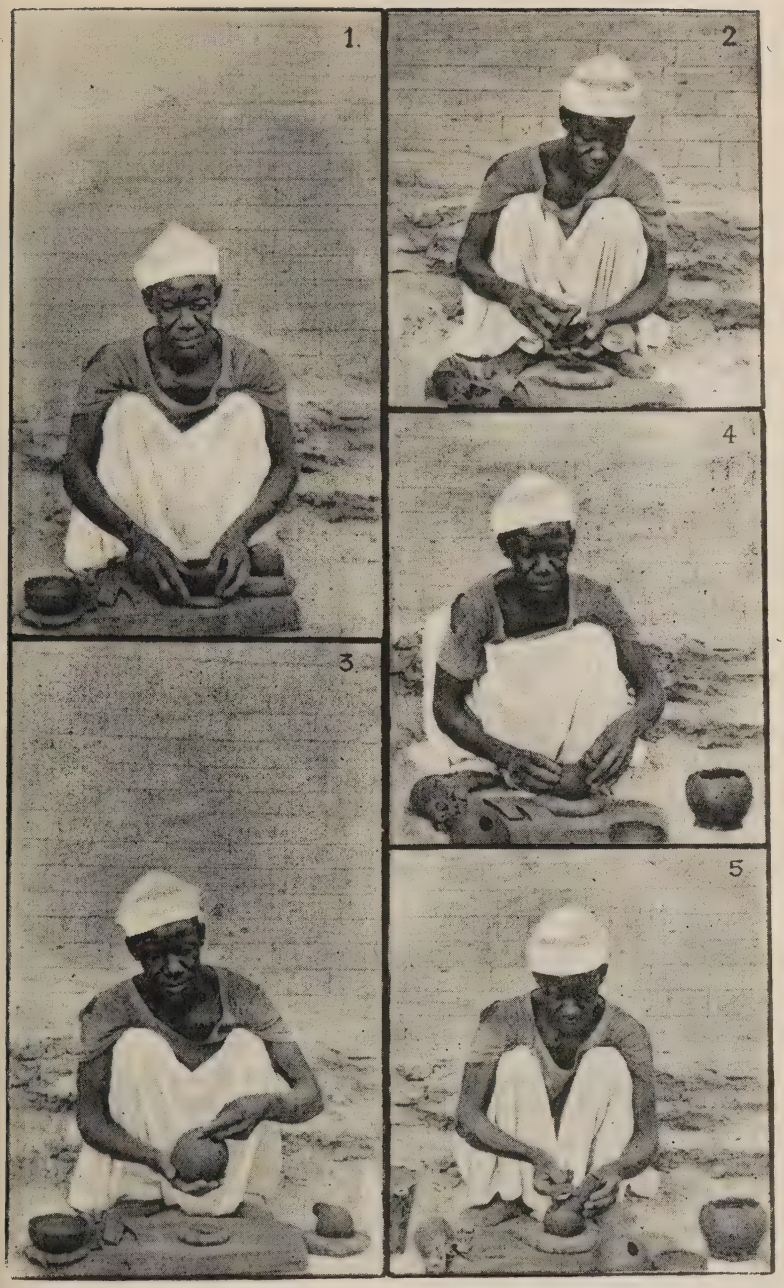

Plate I.

the surface of the pot with a sharp-pointed piece of iron. The polishing is done with a small pebble or the shell of a land snail. Pottery discovered here in the Sudan, and supposed to have been made 4,000 years ago, was polished in a similar manner, and this form of polishing is still practised in Egypt. Plate 2, No. 1, shows the pot finished, and No. 2 the various stages in the evolution of the coffee pots and the small pad on which it is necessary to place them owing to their shape.

One man will make about eight of these pots in one day, and their prices vary from fivepence to eighteenpence, according to size and decoration. The position of the potter is characteristic, and all this type of work is done in the attitude shown, which position he will maintain for hours.

The firing is done by heaping the coffee pots together on the ground, about twenty being prepared at each firing. They are covered over with asses' dung, which is used for fuel, and burned. No special kiln is made, and the firing is accomplished in from two to three hours.

Pottery now made at the Omdurman Technical School, which is connected with the Gordon College, is of a different type altogether and consists of articles which were formerly made in Egypt, and previous to the founding of this pottery department at Omdurman were imported from Egypt. The vessels are commonly known as "gulars" and "zeers," and are used everywhere in the East, both for storing and cooling water. The gular is a basin-shaped article with a long tapering neck, and when filled with water is usually placed in a current of air which lowers the temperature of the water inside. Their capacity is about half a gallon.

Zeers are usually used as filters, and hold about ten gallons of water. They are shaped like inverted cones with a flattening out at the tapering end. The neck is brought into a narrower circle than the middle diameter, and its shape and size are as shown on plate No. 3. Various other articles made here can also be seen in this picture. Wave and spiral designs are occasionally worked round the necks of these zeers with the teeth of a comb, as they are slowly revolved round on the wheel. Their weakest point is round the joint where they are built up, the weight of the water breaking them occasionally. The zeers are usually swung in a wooden stand which holds them round the largest diameter, a bucket being placed under the zeer which takes the filtered water as it drops off the tapered end.

The clay is taken from a local deposit, which was proved to be suitable after many experiments, and is mixed with Nile

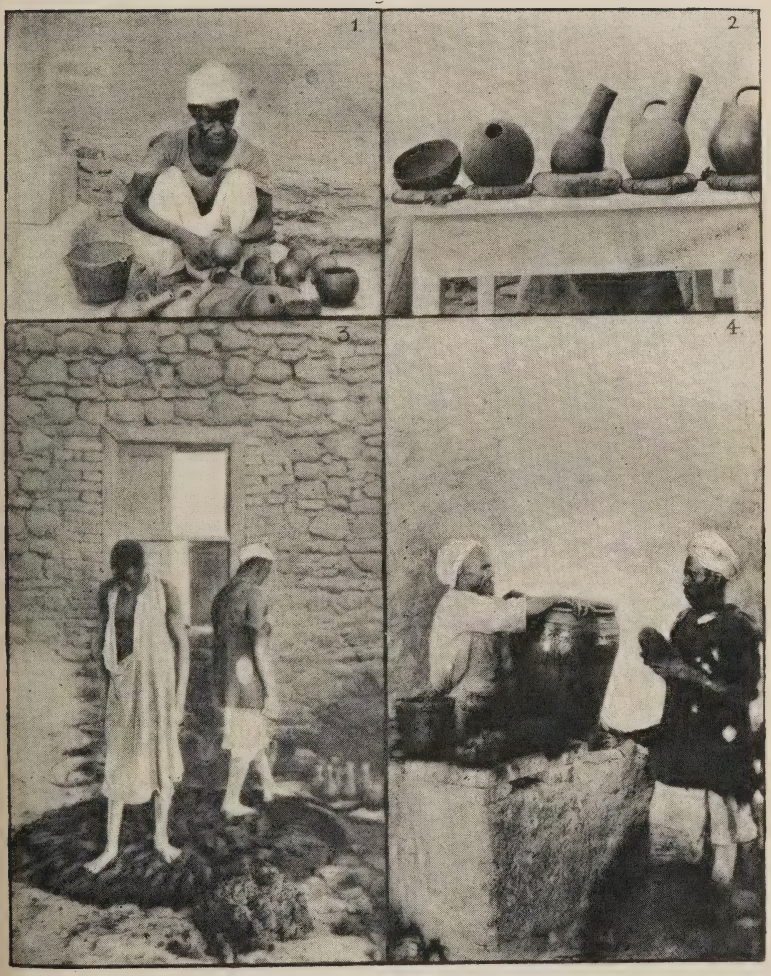

Plate 2.

mud taken from the river bank. This contains a good proportion of fine sand, which gives the ware the porosity required. All the ware is made on the wheel, and in its working is little removed from the primitive methods of potters thousands of years ago.

The clay, which is of a red colour and very plastic, is thrown into a shallow pit about eighteen inches deep and about a yard square. The Nile mud is then mixed with it, the proportions being about three of Nile mud to one of red clay. Water is added until the mixture is the thickness of cream, the process being facilitated by a man standing in the pit and working the mass about with his feet. It is then passed through a fine sieve into an adjoining pit, and the coagulated mass afterwards thrown out on to smooth ground specially prepared and allowed to dry in the sun for a time until the water has nearly all evaporated. It is then taken into the shops and placed on a heap. Plate 3, No. 2 photo, shows the process of mixing the clay in the pits, and the man mixing it with his feet.

Every morning sufficient clay is taken from the heap for the day's working, this is placed on a brick floor and kneaded by the treading and stamping of it by the bare feet of the workmen. This is shown in plate 2, No. 3 photo. It is cut into small sections large enough for the wheel to take, and again kneaded on a small smooth stone, finally being made into a cylindrical shape about eight inches in diameter and nine inches in height. The stone on which the clay is kneaded is shown on plate 3, No. 3, the assistant standing with the prepared clay in his hand ready for the wheel.

The potter's wheel is enclosed by four low brick walls about two feet six inches in height. A plank is thrown across these walls, on which the potter sits working the wheel round with his bare feet. The wheel consists of a circular disc of wood about three feet in diameter, the shaft three feet high, and the disc of beech wood which takes the clay about nine inches in diameter. The shaft of the wheel is inclined at a slight angle from the perpendicular away from the potter, a wheel is also shown in the photo, and the low box-like enclosure in which the throwers work.

As the ware leaves the wheel it is placed under cover from the intense heat of the sun, and also to avoid currents of air, the fluctuations of the temperature being exceptional at certain times of the year. Usually four to five days are sufficient for the ware to dry and it is then ready for the burning.

The kilns are elliptical in plan and elevation, the average size being about ten feet across the major axis; the firing

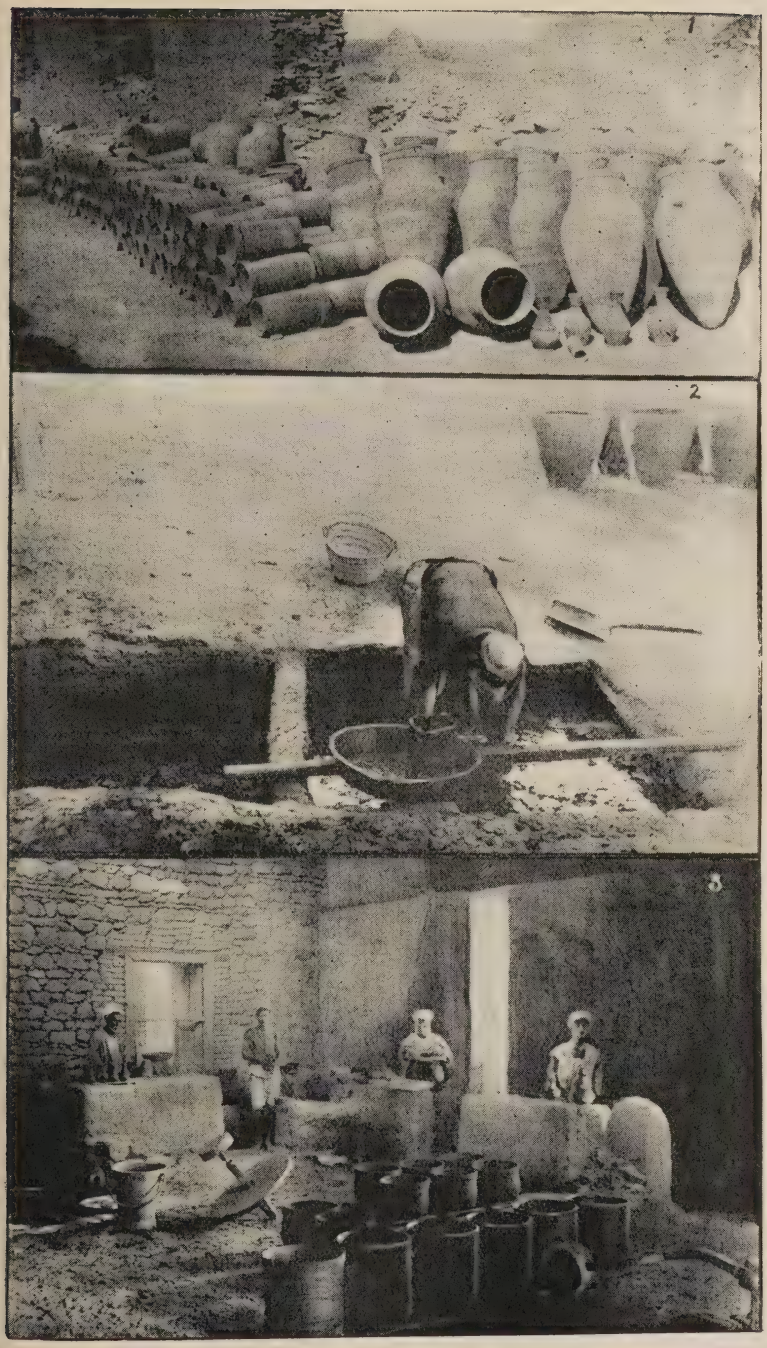

Plate 3.

chamber is below ground level, and the roof thrown across in the shape of a dome, on which are placed the articles to be burned. Openings are left at several places for the flames to enter the upper chamber, and after five hours' burning with a wood fire the upper chamber is covered over with broken pottery and plastered with mud to keep in the heat. About 30 hours later the kiln is unpacked and the fired goods taken out. Unfortunately the position of the kiln and the lighting conditions mitigated against the taking of a photo of the kiln.

The kilns are built of sunburned bricks, which gradually acquire a burnt hardness and approximate to a homogeneous body, the mud, mortar and the bricks fusing together. High temperatures are not possible owing to the lack of coal or oil and mechanical appliances, coal at the present time in patent coal blocks costing over £E10 per ton.

Plate 2, No. 4. A zeer is here shown in the process of making. These are built up in about five throws. After each throw the portion done is taken out and dried in the sun for a short time.

There is a large demand for roofing tiles and irrigation pipes. So far no eminently successful brick has been produced here, and glazing has not been attempted. With the end of the war, and more efficient research made, the Sudan should be enabled to find within its own borders all that is necessary for the building up of a ceramic industry.

REMARKS AFTER READING PAPER.

By W. Emery.

There are many interesting points arising out of Mr. Stirk's paper. I will mention a few, and no doubt others will occur to many of you. The shape of the coffee pot is quite unusual and distinct from anything made in the Potteries. The sectional method of making is quite novel, but perhaps not quick enough for those used to mechanical help. The method of polishing is the one in general use by native potters, the South Americans and the potters in the Philippine Islands I know still use it. Considering the body mixture and the firing conditions the colour of the fired article is remarkable. You will notice that immediately workmen were imported from Egypt they brought with them totally different methods, preparing their clay by blunging, treading and wedging, and using the kick wheel for throwing. In Derbyshire, Devonshire and other counties where crude pottery, *e.g.*, milk pans, etc., are made, arrangements quite as crude can be seen at work. Those of you who

were present at Mr. Acton's lecture on Roman Pottery will recognise a great similarity between the Roman kilns and those used by the Egyptian potters at Omdurman.

Mr. Stirk need not be pessimistic as to the future of the Sudan pottery industry; their methods, though essentially crude, are sound in principle. Workmen capable of producing small art ware like the coffee pots and large zeers, some of which are forty inches high, are pottery craftsmen just as truly as the finest painters or decorators, and if their skill can only be diverted into other directions good results are sure to follow.

Dr. J. W. MELLOR:—I think I can explain why the Sudanese use the round bottomed coffee pots, it is to allow them to be heated up rapidly. In chemical ware, both in glass and porcelain, vessels which are likely to be subjected to sudden heating have a similar shape.

XXI.—Note on Electric Furnace Treatment of Refractories.[1]

By R. S. HUTTON, D.Sc. (Sheffield).

WHEN accepting the invitation to present a note on this subject I had hoped to have an opportunity of adequately collating and completing some experiments on the treatment of several refractories, but unfortunately this has been impossible as I have lately been fully occupied with quite different work. It is, therefore, with some diffidence that I venture to make this communication, and must trust to the Society's indulgence for its sketchy nature.

In general engineering practice, materials which have to fulfil any desired purpose are expected to withstand test conditions far more severe than they will be submitted to in subsequent use, and, however Utopian such a demand may to-day appear when applied to the refractories used in furnace construction, I venture to believe that it should prove a useful ideal to keep before us. When one considers that the temperature of the open hearth steel furnace is somewhere in the neighbourhood of 1,650° C, and that refractories in general use for the construction of these furnaces are seldom produced or tested under much higher temperatures, one must surely admit that, however serious the difficulties to be encountered, it is imperative that attempts should be encouraged to provide a higher "margin of safety" for the refractories now demanded for fuel heated furnaces.

That materials are not wholly lacking is obvious from the scientific work already available; one only needs to mention the melting point of pure oxides: alumina 2,050°, magnesia 2,800°, zirconia 2,563°, and to remember how much has been achieved with silica, which melts probably at 1,780°, to encourage the imagination.

Certainly the problem is not simply the replacement of one material by another, but I know of no published work forming a thorough investigation of the production of refractory materials from any one of these super-refractory oxides.

One of the chief hindrances to rapid progress lies

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1 See also Hutton, TRANS. V., 110, 1905-6.

undoubtedly in the fact that so many investigations are limited to temperatures obtainable with fuel heating, and although electric furnaces have in recent years come more and more into use for testing purposes in the laboratory, far too little seems to have been done and to be in progress in applying in works or laboratory the electric furnace to the preparation of refractories, and the firing of products made from them. Is it too much to hope that in a short time material will be available for industry in the form of bricks and other articles made from highly refractory bodies and guaranteed as having been subsequently fired in its formed state at 2,000° C.?

For the past 10 or 15 years most of the conditions have existed necessary for industrial investigation and, if successful, for the immediate industrial exploitation in this country of such electric furnace processes—electrical engineering has progressed quite far enough to offer every facility in the provision and regulation of suitable currents on an adequate scale—and now the new spirit of progress awakened by the war and the almost complete disappearance of any imminent danger of financial ruin by foreign friend or foe would seem to prove the time suitable to seriously consider such possible developments. Encouragement may be found in the successful development in this country during the past 15 years of the manufacture of the most complex shaped products of vitreous silica. Until 1902, this material was only worked in the laboratory by the tedious and expensive fusion with oxy-hydrogen blowpipes, but the application of the electric furnace enabled large masses to be brought into the plastic condition and difficulties of working, probably far beyond those which would be encountered in the making of bricks and other ordinary refractory shaped articles, have been overcome and manufacture carried out on a relatively large scale.

A rich harvest can undoubtedly be obtained from well-planned industrial research on some of the super-refractories and the indirect benefit which would result by the manifold application of such material is quite beyond estimation.

It is up to the industry to demand that such laboratory equipment as exists be applied to investigating these problems. It is also desirable that some of our municipal and other electric supply stations should follow the example of the U.S.A. and provide facilities for the carrying out of industrial research of this nature in the immediate neighbourhood of their power stations, where, during ordinary hours, small scale furnaces could be run, and at week-ends or other times of slack demand, relatively large electric furnace trials would be possible; in this way in America new industries seem frequently to have been

attracted as permanent customers of such progressive power supplying corporations.

The subject is almost untouched, so, fully conscious that such preliminary work as I have done is incomplete and of little value, I venture to briefly summarise a few of the lines of experimenting available.

The scope of electric furnace treatment may be divided into two branches: the preparation of raw material and the firing of formed products.

1.—Preparation of Raw Material.

Here probably the principal advantage which the electric furnace might offer is the facility with which the material can be shrunk owing to the higher temperatures which can be readily obtained; but one should not lose sight of the possibility afforded of purifying the raw material and thus rendering it more refractory. This latter process has been commercially carried out in the case of alumina both by the Norton Company for the production of alundum, and also by H. M. Hall for removing silica, iron and titanium preparatory to using the purified oxide for the production of aluminium.

Since a selective reduction is often possible by heating the ores to a high temperature with sufficient carbon to remove the iron and other more readily reducible oxides, similar procedure in the case of zirconia and magnesia might doubtless prove valuable.

In cases where actual fusion of the refractory oxide, etc., is desirable the arc type of furnace will generally prove the most useful on account of the facility with which a large energy consumption can be effected in a small space. Many of the simple types of vertical arc furnace as used for calcium carbide manufacture[1] can be employed, and advantage taken in the design to enable the ore itself to form the effective furnace lining, thus obviating some of the great difficulties in finding suitable refractories.

For laboratory or small scale experimenting such a furnace can readily be erected. For instance, I have in successive runs melted some quantity of pure magnesia in a small furnace constructed with a vertical carbon rod 4 cms. diameter, 60 cms. long, forming one electrode, and a graphite plate embedded in retort graphite supported on a piece of boiler plate for the other electrode, the enclosure, about 30 cms. square or diameter, being made either with magnesia bricks or by a tube of sheet iron. As a typical result an average of 400 amperes at 55 volts for

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1 See E. K. Scott, *Trans. Faraday Society*, I, 289, 1905.

46 minutes gave a product of 2,470 grammes completely fused lump plus 2,200 grammes of conglomerated highly shrunk oxide. Taking both products together about 3·6 K.W.H. per kilo as against Scott's 3 K.W.H. per kilogramme.

The efficiency, measured as weight of product per kilowatt hour, is, however, seldom anything like so good in an arc furnace as in a resistance furnace, where the working is more quiescent and the heat insulation is better and disturbance of the material under treatment much reduced.

A small scale equipment which was run for some time, producing in a series of trials about half a ton of highly shrunk magnesia, consisted of a vertical carbon rod 2 cms. diameter, 50 cms. long, gripped at each end in large block of graphite and run for two hours with 400 amperes at 30 volts whilst completely embedded in the material under treatment. The product in this case was not fused, but was recrystallized and highly shrunk, and both in density and general behaviour closely approached the melted oxide.

The energy consumption in this case, despite the very small scale of the experiments, amounted only to 1·17 K.W.H. per kilo of shrunk material. Quite similar results are achieved with a carbon plate 10 cms. × 30 cms. and 5 mm. thick, heated horizontally or vertically, and in all cases surrounded for a considerable distance by the material under treatment.

2.—Firing Finished Material.

Whereas even for a manufacturing scale, plant in use for other electric furnace work can be applied without much difficulty to the treatment of the raw material of a refractory nature, there are relatively few well-tried designs of furnace available for the high temperature treatment of bricks or other similar products, but the demand can certainly provide the supply, for there is no great inherent difficulty other than the will to try.

For small scale experimental work, which must obviously precede any attempt at industrial exploitation, much useful assistance can be obtained from the work carried out at the National Physical Laboratory[1] and elsewhere.[2]

Several methods may be briefly summarized as follows:—

(1) Deflected arc, or radiation from open arcs. This was employed in its simplest form by Moissan in his

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1 See papers by J. A. Harker, Ezer Griffiths and E. T. Griffiths, also by W. Rosenhain and Prior *Trans., Faraday Society.*

2 R. S. Hutton and J. E. Petavel, Inst. Elect. Engineers, 32, 222-247, also Hutton and Patterson, *Trans. Faraday Society*, 1, 187-196, 1905, and H. C. Greenwood and Hutton, *Journ. Inst. Metals.*, 1917.

memorable chemical work, and one of its more highly developed forms is seen in the excellent illustration of the Rennerfelt furnace. (See J. W. Mellor, TRANS., xvi, 92, 1916–17.) I have used this method for experimental purposes for building up small silica tubes by feeding a mould packed with quartz and provided with a carbon core under an ordinary arc, and the method with suitable development may doubtless be of use in special cases.

(2) Carbon tubes or other similar resistance furnaces. Since these form an actual chamber in which the material can be fired and are suitable for definite and easily regulated temperature conditions, they afford valuable assistance in experimental work.

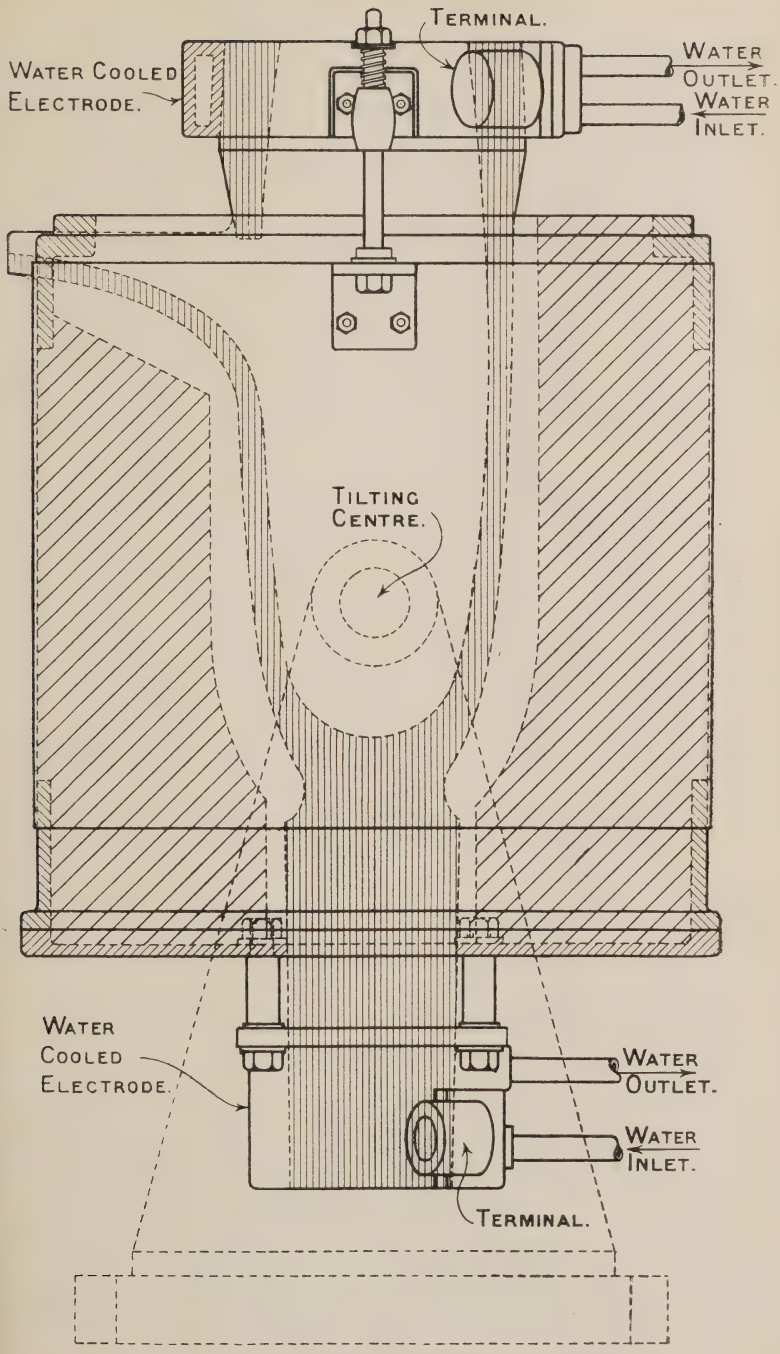
(3) Carbon plates or rods coated with or embedded in carborundum and held in graphite water-cooled terminals, form useful radiating surfaces for heating chambers in laboratory investigation, and although in their primitive form the life is relatively short when used at temperatures of 2,000° and over, for such work they are easily renewed without great cost and with suitable modification might form the basis of a more permanent technical furnace.

In conclusion, I would urge some members of the Society to direct their attention to the possible future development of super-refractories by the application of the electric furnace, and would suggest that rapid progress is possible, firstly, by claiming that full use be made for such work of the equipment already available in some University and other laboratories, and, secondly, by installing in their own works, or in some of the special laboratories devoted to research on refractories, suitable plant for larger scale electric furnace trials.

DISCUSSION.

Captain C. W. SPEIRS, M.I.E.E.:—I have used the small electrical calcination furnace sketched on the board by Dr. Hutton for 15 years. The chief objection to such a furnace is that its capacity is very limited; there is also a marked difference in the degree of calcination, varying with the distance of the material from the source of heat. It is, however, very suitable for laboratory work.

The following particulars of a Patent No. 24,626 (1912) for a plumbago crucible, heated electrically, suitable either for


TERMINAL.
WATER COOLED ELECTRODE.
WATER OUTLET.
WATER INLET.
TILTING CENTRE.
WATER COOLED ELECTRODE.
WATER OUTLET.
WATER INLET.
TERMINAL.

calcining refractories or melting metals, may be of interest to the members.

Water-cooled terminals are fitted to extensions at the top and bottom of the crucible, and any temperature up to that required for melting steel can be obtained.

The temperature is under control between very narrow limits.

I am at present experimenting with electrical furnaces of this type, using crucibles or troughs of a special shape, and hope to produce a plant for melting at least one ton of metal per charge on a commercial basis. Providing a suitable refractory lining for the crucible can be devised, there should be no difficulty in using this furnace for melting steel. The lining for such a purpose will probably have to be made from "electrically shrunk refractories."

Mr. COSMO JOHNS:—I should like to sound a note of encouragement. There is an insistent demand, that has not begun to be met, for refractory products with properties not possessed by, or superior to, those on the market now. The progress of the metallurgical industries is largely conditioned by the nature of the refractory products commercially available. Stability at high temperatures is one of the chief properties sought for. Fused lime, alumina and magnesia, if they could be produced on a commercial scale, would probably give what is required. Dr. Hutton is one of the pioneers in experimental work in this direction, and his description of his early investigations was most interesting. The commercial side of the problem, however, resolves itself into the possibility of obtaining cheap electric power in this country. It is however reasonably certain that the manufacturer who does succeed in surmounting the technical difficulties, will be surprised at the magnitude of the demand and the success that will attend the putting on the market of refractory products made from these fused oxides.

Mr. E A. COAD PRYOR:—We have been working on problems connected with refractory oxides for the past two or three years at the National Physical Laboratory. As Dr. Hutton stated, the starting point of the work must of course be the production of the pure material, and in the case of zirconia we have worked out a process for the preparation of the oxide in a high state of purity. When working with the crude oxide, however, the process of fusion produces a body considerably more refractory than the unfused material, many of the fluxes volatilizing and coming off in dense fumes during the process.

As Dr Hutton remarked, the process of fusion is more simple than most people supposed. We have used an ex tempore

apparatus very similar to Dr. Hutton's, only we have used a horizontal rod instead of a vertical rod. After the fusion has begun the rod may be withdrawn and the fused oxide will act as the heating element. (All bodies are conductors at sufficiently high temperatures, the refractory oxides in particular having extremely high negative temperature coefficients.)

With regard to the furnaces available for rather larger scale production I should like to draw attention to a furnace described by Mr. Fitzgerald in America some time ago.[1] His heating elements consisted of grooved arch blocks of graphite which interlocked and formed the roof of the furnace. I do not see any reason why that principle should not be extended more or less indefinitely. As a matter of fact we have designed a furnace at the National Physical Laboratory for use at high temperatures suitable for work in this connection.[2]

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1 *Transactions of the American Electro-Chemical Society*, 1911.

2 Described in a paper by Dr. W. Rosenhain and Mr. E. A. Coad-Pryor to the Faraday Society, in February, 1918.

XXII.—Refractory Materials in Gas-works, from a User's Point of View.

By Jno. P. Leather.

In a gas-works profits are said to be made or lost in the retort house, and the central point in the retort house is the retort bench constructed of refractory materials. On the proper quality, disposition and use of these materials largely hangs the success of the whole operations of a gas undertaking.

The main structure and walls, the producer, the regenerator, the combustion chamber, and finally the retorts themselves might each be separately considered. I propose, however, to deal first with certain primary characteristics which are required in all these situations, and afterwards to refer to other properties desirable in special positions.

(1) Capacity to resist deformation by the pressure of the superstructure when exposed to an elevated temperature. It is not sufficient to speak of the temperature of fusion or softening. Any test of fusibility ought to be accompanied by a deforming force, and in this again the time should be taken into account. The testing of firebrick as at present carried out attempts to discount the effect of time and pressure by requiring the material to stand for a short time and with very little deforming force a much higher temperature than appears in practice. The argument apparently is this: A gas retort which sustains for a lengthy period the stress of actual work at a temperature of, say, 900° C., gives way in a short time with a very small stress at a higher temperature of, say, 1,400° C. Therefore, if a material does not show signs of fusion in a short test at, say, 1,700° C., it will probably stand indefinitely in actual work. This argument may have a certain amount of truth in it, but is not entirely convincing unless actual experience or experiment discloses some definite relation between these various elements of temperature, time and stress. Thus we are driven, if we seek to improve and progress in our methods, on the old way of using one material, and if it fails trying something else. Failures are, however, so expensive, that we prefer to keep to old tried materials and leave someone else to experiment. This is inimical to progress.

In the combustion chamber the bricks have to stand a temperature of at least 1,500° C. It would be better if we could rely on them not yielding at even 1,600° or 1,650° C., as in order to have a sufficiently high temperature at every point some parts must be considerably hotter. Often heats have to be checked for no other reason than the fear of damage to the brickwork. In many settings the walls of the combustion chamber support the upper tiers of retorts, and it is possible that in places the weight may exceed one ton per square foot. It requires a high quality of silica brick to maintain this stress for an indefinite period at 1,500° C.

Here I would note that there is a great difference between a brick wall heated on both sides to the same temperature and one which is at a high temperature on one side and a low temperature on the other. In the latter case only a part of the brick is at the high temperature, and a much higher temperature can be withstood without yielding.

(2) Secondly, it is important that the size of the material should not alter otherwise than by the unavoidable dilatation with heat and the subsequent resumption of the original size when cooled. The liability of refractory materials to permanent change of size, either by expansion or contraction, is very inconvenient, and particularly so in vertical retort settings. As some parts of the setting are necessarily at a much higher temperature than others, irregular expansion or contraction leads to cracked or leaky retorts, and in the generator to by-passing of secondary air with resultant losses difficult to remedy and costly in their effect. Whether this defect is to be obviated by increased temperature in the manufacturer's kiln, or by the different choice of materials, the need of eliminating change of size in use is imperative. It must be remembered that a contraction of 0·5 per cent. in a 25-foot retort amounts to 1·5 in.

(3) The third desideratum is a material which will be less affected by the chemical action of dust, slag and reducing atmosphere. If a material could be found to resist these influences at a high temperature it would be very convenient and advantageous to the gas-works manager. But, although I am here in the rôle of a user, I feel that this claim may be pressed unduly. The brick manufacturer may, I believe, rightly reply that it is the duty of the user to avoid in his furnaces the production of slag, and so arrange that dust does not come into contact with bricks at a high temperature. With regard to reducing atmosphere, apart from the inside of the retort, the chief reducing agent is carbon monoxide. Research on this matter is not complete, but from my experience I am inclined

to think that carbon monoxide has not a great effect on refractory material in the absence of dust, *i.e.*, in the absence of excessive quantities of oxide of iron and like substances. I do not think that a user ought to ask the manufacturer to provide a brick with special qualities to overcome difficulties which may be avoided by the method of working. It is a well-known fact that there is little or no direct chemical action between two solid substances. In order to bring about such mutual action it is necessary either to introduce a liquid which has a solvent action on one or both substances, or else to raise the temperature until one of the substances begins to fuse. Dust has little effect on firebrick if the temperature does not approach its melting point.

If flue passages are of sufficiently large dimensions to avoid a cutting draught a minimum of dust goes forward into the parts of the setting where the temperature is high. In the producer dust is unavoidable, but it is not in the producer that we require the heat but in the retorts. The temperature in the producer should be kept so low that the ash does not melt. This may be brought about either by the use of sufficient steam, or, as I believe, first proposed by Siemens, introducing waste gases into the producer with the primary air. Inside the retort the atmosphere is much more strongly reducing than in the furnace or flues, and I have yet to see evidence of the inside of the retort melting under its influence.

(4) I have already referred to the crushing stress which firebricks should be able to stand. This is seldom as high as two tons per square foot, and is therefore much less than ordinary red bricks are regularly subject to. Such a stress is not important except when combined with elevated temperature. Mechanical strength of another kind is, however, called for in the producer. Here it is not always possible to avoid all formation of slag which melts and corrodes the surfaces of the bricks. The slag runs down until it reaches a part where the temperature is lower, and then it clings to the brickwork and has to be removed by the process of clinkering. The material should therefore have great tenacity.

(5) Conductivity. In the regenerator and in the walls of the retorts greater thermal conductivity would be desirable if it could be obtained without countervailing disadvantage. It would, however, be necessary to guard against uneven expansion if the high conductivity bricks had a different coefficient of dilatation from the other bricks used in the structure. Such uneven expansion might lead to cracks or open joints through which air could pass and neutralize the whole value of recuperation.

(6) Porosity. In the intermittently charged retort the sudden introduction of cold coal into the retort previously raised to its maximum temperature introduces a condition which, if the material is too dense, is liable to cause cracks. To secure that the retort shall not crack with sudden change of temperature our standard specification demands a certain porosity. Possibly this diminishes conductivity, but of two evils a leaky retort is worse than low conductivity.

To recapitulate, the chief requirement in a firebrick used in a retort setting is that it should not alter in size or shape under the combined influence of pressure and high temperature, and for some purposes the desiderata are a better conductivity and maintenance of integrity under sudden changes of temperature.

Firebricks are also used in gas-works for carburetted water-gas plants. The chequer work of superheaters or fixing chambers are subject to the action of oil vapour at a varying temperature of from 650° C. to 800° C. Some bricks appear liable to disintegration under these conditions, probably due to imperfect burning in manufacture.

Lastly, I might draw attention to the desirability of regular size and accuracy of shape in fireblocks and bricks. Probably this is largely a question of securing an even and sufficient temperature in the kiln, though possibly sometimes not sufficient care is taken in the preparation of the clay before moulding. These points I leave with manufacturers, with the hope that they will not be content to remain on the lines of their forefathers, but ever seek to progress.

DISCUSSION.

Mr. E. Escott Wood:—I should like to emphasize the remarks of Mr. Lee. At the present moment the variations of temperature in coke oven walls and flues are almost entirely due to the problem of getting satisfactory deliveries of slack. For instance, at our own plant the shortage at Easter reduced our number of ovens drawn by 50 per cent. This means in working a considerable reduction in temperature, then when slack supplies get more normal up go the heats again. This variation in heat alone is a severe trial on the brickwork, and is, I think, another point which as a Refractory Materials Society we should keep before us.

XXIII.—Note on a Firebrick from the crown of an Electric Steel-melting Furnace.

By W. J. Rees, F.I.C.
(Department of Refractory Materials, University of Sheffield).

In view of the fact that progress in the design and construction of electric furnaces for steel-melting is to some extent limited by the inability of the available refractory materials to withstand the high temperatures and other conditions met with, it is important to place on record trials of refractories which meet with any measure of success.

My attention was recently drawn to the firebrick crown of a half-ton Greaves-Etchells electric steel furnace. This crown had given what was regarded as excellent service, having lasted for 145 charges.[1] In the same furnace and under precisely similar conditions crowns of high grade silica bricks had given a much shorter life. The general conditions of the furnace during operation were quite normal. An analysis of one of the bricks gave the following results:—

Silica	51·83	per cent.
Alumina	38·73	,,
Titanic oxide ...	6·68	,,
Iron oxide (as Fe_2O_3)	1·56	,,
Lime	0·31	,,
Magnesia ...	0·19	,,
Potassium oxide ...	0·59	,,
Sodium oxide ...	0·32	,,
	100·21	per cent.

The softening point of the brick was found to be at cone 37.

In the fluxed end of the brick an abundant development of sillimanite was found.

On investigation it was found that these bricks were made from the newly discovered refractory bauxite clay, which overlies the Millstone Grit lavas in N.W. Ayrshire, and to which reference was made by Messrs. Hinxman and MacGregor in their paper on the fireclays and ganister of the South of Scotland, read before the the Glasgow Meeting of the Section.

1 A second crown of the same material has lasted 130 charges and gives promise of a much longer life.

Mr. G. V. Wilson, of the Scottish Geological Survey, who with the late Dr. C. T. Clough investigated these fireclays, informs me that this clay is of the highest quality near Saltcoats and Stevenston, and that further east towards Kilmarnock and also at other localities in Arran, Sanquhar and Stranraer the softening point is several cones lower. In all probability the seam extends under the whole area between Saltcoats, Kilmarnock and Troon. The clay is very hard and well-jointed, has a conchoidal fracture, and contains very numerous spherulites of bauxite. It is almost non-plastic, so that in making it into bricks, etc., it is necessary to use a proportion of a refractory plastic clay as a bonding material. Samples from various locations tested have been found to contain up to 50 per cent. of alumina and up to 10 per cent. of titanic oxide, and to have softening points of from cones 32 to 38.

The seam is now being exploited at several points, particularly on its northern outcrop. It will undoubtedly prove of great value in metallurgical and other furnaces where highly refractory materials are essential to successful and economical operations.

XXIV.—An Advance towards greater Economy of Fuel and Increased Output in the Deadburning of Magnesite and Dolomite and the Burning of Cement.

By E. Steiger.

I AM indebted to your Secretary for the privilege of bringing to-day to your attention a new type of kiln for the calcination of lime, dolomite, magnesite, Portland cement and kindred materials.

For many years the bottle kiln had held sway in the calcination of the above materials, and does so to this day for lime and dolomite. Its cost of installation was comparatively inexpensive, the product satisfactory, the fuel consumption moderate except where high temperatures were asked for; but the labour bill has always been a heavy item in the cost of production, and the output of the kiln is strictly limited.

Of late years the horizontal rotary kiln has become a formidable competitor. It has gained the ascendency in the cement making. It has supplanted the various types of shaft kilns and also the chamber kiln in the large works, notwithstanding the very heavy initial cost of installation. Only in the smaller works have the older kilns been retained, and by dint of improvements here and there owners have been able to successfully hold their own in price and quality against the rotary cement.

The application of the rotary kiln has also been extended to the deadburning of the ferruginous magnesite found in Austria and Hungary and, I believe, proves satisfactory. In Canada and the United States its use has become general for the local magnesite. Like Greek ore, the American and the Canadian magnesite contains little or no iron, and in order to approximate it to the Austrian stuff iron in some form is added to the crushed magnesite before the first burning.

With regard to the use of the rotary for the burning of lime, a recent report in the *Rock Products and Building Materials*, a Chicago paper, on the methods of calcination of

lime in America indicates that the lime becomes overburnt and quick setting.

The striking advantages of the rotary kiln, which have conquered the cement industry, are: Great *productiveness*, which allows of a concentration of production in single large works, on a scale previously hardly dreamt of; automaticity of the process, the elimination of the handling of the material by man and the substitution of the machine, and the introduction of the continuous process. The growing demand for a building material which had become indispensable, called for more modern methods of turning out quantities.

The rotary is, however, very far from being a perfect instrument of calcination. Its temperature is strictly limited. It requires coal of best quality, free of ash. The coal must be dried and ground. The drying means heavy loss of weight and corresponding increase in the cost of fuel. The quantity of powdered coal to be stored is strictly limited, it must be ground from day to day because some of the coal would set up spontaneous combustion already within 24 hours. The utilization of heat is most imperfect, great efforts are still being made to better preserve the heat, of which large quantities escape up the chimney and in the finished clinkers. The installation of a rotary plant is very costly. Its plant is complicated by the coal drying and grinding machinery. Its grinding plant must be more massive than for the treatment of shaft or chamber burnt cement, because the clinker is hard and globular, whereas the clinker of the other kilns is spongy and crumbly. The rotary clinker calls for much more energy and the H.P. is correspondingly heavy. The clinker, besides being hard, is overburnt and yields a quick setting cement, which requires the admixture of gypsum or water as countereffect. The maintenance and repairs charges are a heavy item in the cost of production and higher than in the old-fashioned kilns.

For twenty years or more the rotary kiln has absorbed the attention of the kiln engineer, and the shaft kiln has been relegated to a back number. However, it has once again come into its own. The introduction of the mechanical stokers in boilers, and of rotary grates in gas producers and their success, the improvement in the means of handling and transporting of materials by automatic devices have shown the way in which much improvement in the bottle kiln could be made. Two Swiss kiln engineers, Steiger and Frey, set to work, and adapting the principle of the rotary grate to the shaft kiln, together with the introduction of automatic loading and an excellent system of preheating of the air of combustion, they have at one bound placed the shaft kiln into the very front rank and have created

in the "Swiss economic kiln, Steiger's patent," the best type of kiln extant for magnesite, dolomite, lime and cement.

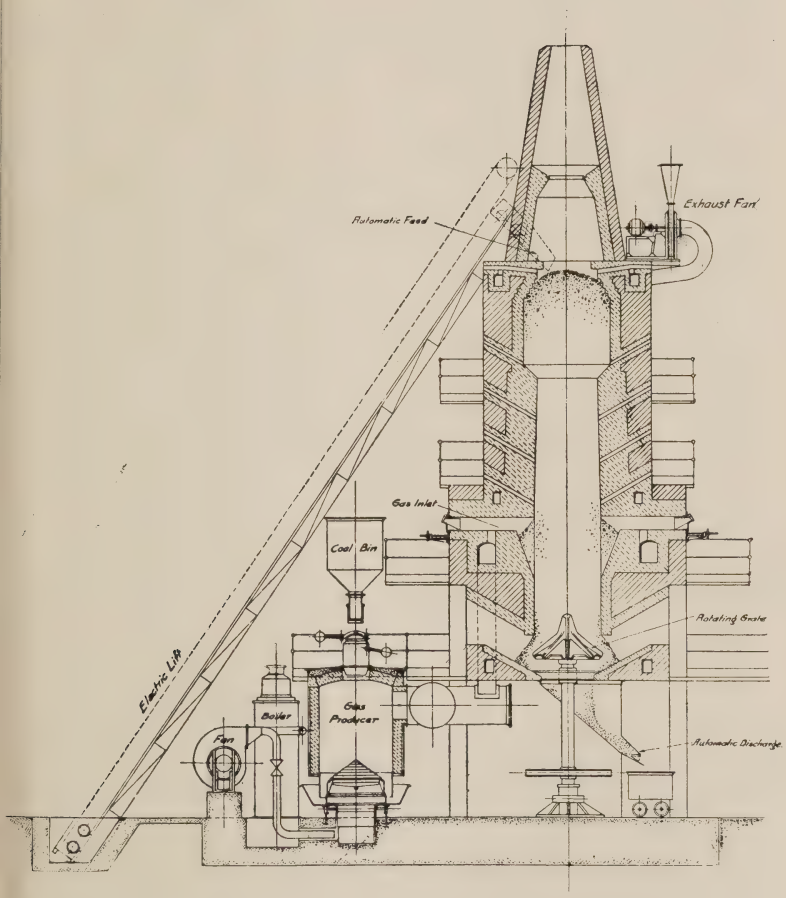
As you are interested in the refractory basic material I shall explain the system as developed for the deadburning of magnesite and dolomite. I am able to speak from personal experience, because I have been instrumental in the adaptation to and the erection of the first kiln for the deadburning of magnesite. It stands on the Island of Eubœa, Greece, and was built in 1915, and taken into use in December, 1915. It has worked two periods of six and twelve months continuously and was only closed down on account of want of transport facilities.

The chief aim of a kiln builder must be to attain the requisite temperature for the work to be done at the least expenditure of fuel, in other words, in the perfect utilization of the heat developed. I have here a drawing of kiln designed for magnesite and dolomite of the purest kind. Its main features are: (*a*) Perfect heating of the air of combustion, (*b*) self-action in loading and discharge. The kiln consists of one vertical chamber without contraction at the hot zone, the wall slightly widens towards the bottom. It is lined in the hottest zone with magnesite bricks, and elsewhere with best firebricks with a backing throughout of a row of secondary firebricks.

The ore is elevated by electric lift and dropped into a charging bell similar to those used in gas producers, in order to exclude all false air. It descends gradually, gets heated by the ascending gases, gives off its carbonic acid and moisture, passes the deadburning zone and finally enters the cooling area. When arrived at the bottom it gets automatically pushed out into a discharging hopper also locked.

The air of combustion is pressed into the kiln by a fan, it enters through six openings at the very bottom controlled by dampers, and is then forced upwards through the column of burnt material, absorbing the heat of the ore and becoming highly heated by the time it reaches the level of the gas inlets. There it becomes mixed with the gas. As a precautionary measure we have a secondary system of air flues which run inside the brickwork about two-thirds way up the kiln, where it doubles back, descends a short distance to emerge through the slits just above the gas ports. The heating of the air is effected by the heated brickwork. These flues are only used should the flow of the air through the column of ore be for some reason or other irregular.

The gas is generated in a producer set up next to the kiln, a short line of brick-lined pipes leading the gas into three flues


Automatic Feed
Exhaust Fan
Gas Inlet
Coal Bin
Rotating Grate
Electric Lift
Boiler
Gas Producer
Fan
Automatic Discharge

arranged in the brickwork; it ascends, absorbing the heat of the bricks, and enters the chamber through six ports. The temperature attained by the use of good English coal is 1,700° C., equivalent to steel furnace heat. The gases ascend, losing their heat to the ore; they become mixed with the carbonic acid liberated and finally leave the kiln at a temperature of 150° C. A suction fan exhausts the gases. You will notice the whole draught and the process of calcination is regulated and controlled by mechanical means which allow of complete control.

So far the process described is the same as you would meet in any up-to-date shaft kiln plant. The novelty of the system is the introduction of the *rotator* at the bottom. It consists of a vertical shaft upon which is fixed a cast steel head of conical shape with ribs on its upper surface. It rotates, moves the finished ore towards the opening and at the same time exercises a grinding action upon any lumps which may have formed themselves in the calcination. The rotating action has the further effect of keeping the column in constant motion, thereby insuring a gradual descent of the ore.

The speed of the rotation is adjustable by means of a step pulley and a variable speed motor. As a rule the shaft rotates once in forty minutes. The movement is so slow that the wear and tear on the head is not noticeable. The head in the magnesite kiln has never been changed since its installation, thus showing that the temperature at the bottom of the chamber is in no way detrimental to the steel.

The advantages of the rotator are manifold:—(1) It seals the kiln effectively. It renders drawing doors and the raking out of the ore by hand superfluous. No cold air can rush in and lower the temperature. There is no danger of bringing down a lot of unburnt stuff every time the fireman draws, thereby the formation of cavities in the column, which often disturb violently the calcining process, is obviated. The production of underburnt material drops down to negligible proportions, whereas a percentage of 10 to 20 per cent. of underburnt stuff in a hand-drawn kiln is not out of the usual. (2) As a natural sequence you have a regular working of the kiln and an ideal utilization of the heat generated expressed in the low percentage of fuel used. (3) An increased output of burnt material. (4) A vastly better and more uniformly deadburnt stuff.

The output of the natural draught kiln which the new kiln was destined to replace, was 3 to 4 tons of deadburnt

material a day. The new kiln has done 14 tons a day, or over 4,000 tons in a twelvemonth, an increase of 300 per cent.

The fuel consumption varied in the old kiln from 35 to 40 per cent. It has dropped to under 20 per cent. per ton of finished material. Compare this to the 35 to 40 per cent. of coal required for the deadburning of magnesite in a horizontal rotary and the 100 per cent. of fuel used in a down-draught direct-fired kiln. The ore remains 35 to 40 hours in the kiln. Fifteen to twenty hours are required for heating up, 3 for deadburning, and 15 hours for cooling.

The economy of labour is not so striking where you have a single kiln to deal with, but with the growth of the plant it becomes very marked, as all hand labour is eliminated, the lifting of the ore, the tipping into the kiln, the handling of the coal, the discharge of the finished material, everything is done by machinery. The power required per kiln is only 30 H.P.

It is of importance that the ore treated in a kiln working at such high temperature should be as free of impurities as possible, because the latter reduce the sintering point below the temperature of the kiln and will cause serious trouble. For the less pure ore requiring lower temperatures a different construction is resorted to.

I have dwelt at some length on the subject of the gas kiln. Permit me to say a few words about the new Portland cement kiln. In a cement kiln we deal with temperatures of about 1,350 to 1,450° C. The producer gas is therefore dispensed with, and coke or coal, as the case may be, mixed with the cement slip is used. But whereas it has been customary to charge the fuel and the cement slip in alternate layers, we mix the coal or coke reduced to peasize with the slip and form the mixture into briquettes in a brick press. This method has been rendered possible by the perfect preheating of the air of combustion. You will readily admit the advantage thereby gained, but we are going a great step further; whereas in all cement kilns hitherto employed only the best of fuel is just good enough, coal or coke for the shaft kiln, coke for the chamber kiln and coal for the rotary kiln, we make use of *any kind of coal or coke*, from the best down to coal containing 30 per cent. ash, lignite and brown coal, thereby freeing the Portland cement making from its bondage to the best of coal and making it possible to erect works in the neighbourhood of cheap local sources of *inferior fuel*. It will mean a popularizing of the manufacture of cement such as nothing else will accomplish. It will bring the cement into common use where it has been a luxury, for reason of its high price.

The percentage of fuel added to the slip depends upon the heating properties. In a plant erected at Nice and worked for the last six months a local coal containing 30 per cent. of ash is used, and the proportion of fuel to the finished clinker is under four cwts. per ton, an achievement which no other kiln working with the very best of fuel has ever attained. It is safe to say that with a ton of best English coal (not dried) seven tons of clinkers could be produced as a regular performance, and with a ton of coke six tons of clinker.

The kiln is the same in arrangement as the gas kiln but without the gas producer. The structure is higher and the diameter of the chamber larger. The sintering zone is about seven feet from the top and is three feet high, thus leaving a greater space below for the cooling, which is necessary, because the rate of progress of the ore in the kiln is considerably greater than in the gas kiln. The rotator is retained, also the forced draught by pressure and exhaust fans. The utilization of the gases is so thorough that the latter leave the kiln at less than 150° C.

The output of such a kiln is astonishingly large. The kiln at Nice above referred to, working a coal of 30 per cent. ash, produces *daily 45 tons* of cement clinker; with a good class of fuel it would do readily 50 tons. I believe I am right in saying that this performance is twice as large as the best of bottle kilns has done hitherto. It is five times as great as the output of a chamber kiln, and one-third the output of a modern horizontal kiln of 200 feet length.

The time of calcination lasts about 24 hours, 8 hours for heating up and clinkering, and 16 hours for cooling. Please note the long period of cooling compared to the time allowed in other kilns, especially the rotary, and the great saving in fuel becomes easily comprehensible.

The clinker obtained is of a spongy nature, has therefore the same qualities as the chamber cement clinker, easy grinding, and a slow-setting cement.

The repairs are slight as there is very little to get out of order. The whole of the structure is built of bricks and reinforced concrete with a lining of best firebricks. That mass of steelwork so conspicuous in the rotary kiln is absent, a great consideration at present when steel is scarce and badly needed for other purposes, and when it is a question of erecting a plant oversea. In the "Economic Kiln" steel is only used for binding the structure, for the lift, the platform, the bottom of the shaft. The machinery is as simple as in the gas kiln.

A careful comparison of the costs of installation of plant on the rotary and the economic systems shows greatly in favour

of the latter, and the further removed the site of the plant is from the places of manufacture of the steel and the machinery the greater the advantage becomes in favour of the economic system. I estimate the advantage at 30 to 40 per cent.

The economies to be effected in the cost of production of the cement by the adoption of the economic kiln are equally striking, firstly, there is the saving in fuel, 1½ to 2 cwts. per ton of cement; secondly, it requires only two-thirds of the energy of the rotary kiln system, of every 500 H.P. used in the rotary system 150 H.P. are economised; thirdly, we have a saving of 30 per cent. or more in interest and depreciation. The cost of the finished cement on the economic system should readily be 20 per cent. below the cost of the rotary cement, and the further the plant is from the coalfield the greater becomes the discrepancy in favour of the economic kiln.

I believe that this kiln will prove of special value in the Oversea Dominions. Not only is it economical in the consumption of good fuel but it will work with indifferent fuel now wholly unsuited for cement making, and works can be erected in localities which have been excluded hitherto. An advantage wholly in favour of the new system is the ability of working smaller plants of 300 tons a week and upwards profitably. Not every district in which the suitable raw material and the fuel is available can take up the whole of the production of a modern rotary cement plant, whereas 300 tons is a quantity not beyond the capacity of almost any district.

We are in the midst of a world's war which will affect profoundly the economical conditions of this and all other countries. Fuel will continue high in price, its value has been brought home to all of us, everything tending towards a better and more effective utilization of the heating properties of fuel is to be warmly welcomed. The production of refractory materials is at present making too heavy a draught upon coal and coke. The economic kiln will cut the present fuel bill on an average in half. It is therefore not only the owner of such a plant who will benefit, but the country at large will be a gainer, as the fuel now used in excess will be available for other useful purposes.

DISCUSSION.

Mr. Escott Wood:—With respect to the two kilns which have been compared. Mr. Steiger says that the quantity of magnesite from the new kiln is very much the greater, but gives no particulars as to the dimensions of the two kilns; he certainly should do so to justify his comparison.

Mr. H. E. MASON:—I did not intend to say anything about this kiln; no doubt it has its advantages.

In these times one has to take magnesite of inferior grade; it is almost impossible to obtain pure magnesite, and I should like to know what would happen if inferior magnesite is put in this kiln? It seems to me that with such material there must be a certain amount of clinker in large lumps in this furnace, and when it comes to the bottom in a mass what would happen?

Then the cost of construction. I am afraid the cost of construction would be prohibitive, but the first consideration is: what would happen if you put inferior magnesite into the furnace? In Greece the suppliers would have little or no trouble, as they undoubtedly select the magnesite they use. There is no doubt that with good magnesite the Steiger kiln would give a perfectly satisfactory product, but so also would the rotary kiln mentioned by Mr. Steiger.

Mr. E. STEIGER:—I am sorry that I had omitted to state that the diameter and the cubic capacity of the two kilns are practically the same.

Replying to Mr. Mason's query about the treatment of inferior magnesite in the new kiln, I can assure him that the kiln is in no sense a delicate one, it can successfully deal with inferior ore. In working the Eubœan kiln care is taken to free the stone from dirt and blind matter already at the mine, lumps which are too large for the kiln are broken, and the dust and the fines go to the spoil heap; but otherwise there is no sorting of the material at the kiln, as long as silica and lime are kept within reasonable limits, say an average of 3 per cent. for the lime and 4 per cent. for the silica.

In order to get properly deadburnt magnesite there must be a clinkering action and an accompanying formation of larger lumps. The introduction of the steel head on the top of the rotating hearth serves the very purpose of breaking down these lumps. The stoppages of the kiln owing to the formation of blocks are far less frequent in the new type than they are in the kilns without rotator, because in the latter they must be broken by hand.

The cost of construction is in no way prohibitive. The kiln itself is no more expensive than a structure of similar nature—the extra cost consists of the mechanical parts, the rotator, the fans, and the motors. They probably add less than 50 per cent. to the cost. They are, however, an essential part of the type, and without them the benefits claimed could not be obtained.

XXV.—Silica Products. (I. Raw Materials).

By A. Bigot, D.Sc., Consulting Engineer to the Ministry of Armaments and War Manufacturers.

(Translated by J. A. Audley, B.Sc.)

UNDER this name is described refractory products manufactured with silica agglomerated by means of a small quantity of lime and burned at a high temperature.

The manufacture of silica products is known from the highest antiquity. Mr. W. Burton published in the Royal Society of Arts Journal the result of analyses to which he submitted ceramic objects of different epochs of ancient Egypt.

	Silica	Lime	Magnesia	Alumina	Iron oxide	Alkalies	Loss on ignition
I.	94·00	2·00	1·05	1·80	0·89	0·25	0·11
II.	94·18	1·73	1·82	0·59	1·64	—	0·04
III.	94·18	1·60	0·05	1·93	0·28	1·11	1·00

The Chaldeans, Assyrians, Persians, have made silica products in the form of bricks, blocks, with or without enamel. In 1913 I had occasion to study and reconstitute the frieze of archers of the palace of Darius which is at the Louvre Museum (Memoir read at the Academy of Inscriptions and Belles-Lettres in June, 1913). The bricks which make these friezes are one foot long, one foot or half a foot wide, and three inches thick They are composed of quartz sand agglomerated with a lime analogous to our hydraulic limes.

Their fusion point is 1,730°, measured with French decimal cones of Ch. Guérineau & Co. Analysis showed:

Silica	Lime	Magnesia	Alumina	Iron oxide	Not determined and loss
89·10	5·05	0·62	2·10	2·80	0·31

This industry of silica products, of which traces are recognised twenty-five centuries before the Christian Era, has lasted about four thousand years. It has always remained localised in Egypt, Persia, Palestine, and Asia Minor. The ancients nearly always enamelled these silica products.

The industry of silica products reappeared in Europe in the last century, in the form of refractory pieces destined for metallurgical furnaces; they took a great development in

England, the United States, and Germany. France is tributary to the foreigner for these products. Important efforts are made by the French manufacturers to supply the French market, but the production is still insufficient.

The manufacture of these refractory products presents rather great difficulties because of the variety of the siliceous raw materials and the different ways in which they behave in the fire. The study of these subjects is long and delicate, necessitating the co-operation of the microscope, of analysis, of the furnace at a high temperature, and of a certain number of physical trials. The memoirs which have appeared on this subject, in spite of their importance, have not elucidated the question. A few years ago I studied these questions, and the results of my researches, directed towards practical applications, will contribute, I believe, to the development of the industry of refractories based on silica.

Study of the Raw Materials.

The raw materials which are suitable for this industry are quartzose rocks or sands. Leaving aside for the moment the quartz sands, there is reason to examine the siliceous rocks. They occur in the form of quartz, or quartzite, flint, compact sandstone. But these different varieties affect different appearances and forms; quartz is usually agglomerated in great crystalline masses; quartzites are often in their beds mixtures of quartz and flint, etc.

It is generally admitted that the temperature of the Martin furnace can reach 1,700°; experiments which I made on bricks from arches of Martin furnaces, of which I shall speak in another article, confirm me in that opinion.

The study of siliceous rocks destined for the manufacture of silica bricks permits three series of experiments:

1. Analytical studies. 2. Physical studies. 3. Micrographic studies.

1. *Analytical studies.*—Siliceous rocks include from 95 to 99 per cent. of silica, the remainder being alumina, iron oxide, lime, magnesia, combined water, etc. Quartz materials are the richest in silica, and contain little of foreign substances. The same is the case with calcined flints (silex). Quartzites, on the contrary, always include a notable proportion of foreign matters, which is bound to have an important effect. Lieutenant Bodin, chief of the Section of Building Materials at the Testing Laboratory of the Conservatoire National des Arts-et-Metiers, noticed that certain quartzites heated to 1,600° and 1,650° were covered by a slight glaze of a bright yellowish brown. In the course of my trials I was led to find quartzites producing

the same phenomenon towards 1,600°; these enamelled quartzites, carried afterwards to 1,700°, spontaneously absorb their external enamel and go out of the furnace with their surface clear and matt.

To discover the nature of the foreign elements which are found in the quartzites, I ground some quartzites, and passed them through a No. 200 sieve. The powder was put in suspension in water and the lightest materials were collected while the heaviest remained at the bottom of the receiver.

Analyses of a quartzite and of the very fine material obtained by washing the powder of this quartzite gave the following results:—

	Silica	Alumina	Iron oxide	Lime	Magnesia	Loss on ignition	Carbonic acid
Natural rock ..	95·95	2·65	1·96	0·15	0·08	1·20	not determined
Washed product	86·40	7·60	0·95	0·35	0·20	3·12	0·08

In the washed product 76·90 was free silica, and 9·50 combined silica.

It follows from these analyses that the quartzite tested is a mixture of silica and clay, the natural rock containing about 7 to 7·5 per cent. of clay; microscopical examination of a thin plate cut in this rock shows masses of crystals surrounded by amorphous matter.

The washed product includes about 21 to 22 per cent. of clay, and its physical study gave results interesting for the manufacture of silica products. This material is rather plastic; when taken to a temperature of 1,250° its contraction is 1·50 per cent., at 1,600° its contraction reaches 4·50 per cent., and the piece is completely covered with a thick glaze, yellowish-brown, not crackled. A cone made with this material bends down at 1,680°, whilst a cone made with the original rock bends down only at 1,730°. A cone made with this material, to which 2 per cent. of commercial slaked lime was added, bent down from 1,620°, whilst a cone made from the ground rock, to which 2 per cent. of lime was added, bent down between 1,710° and 1,720°.

It follows from these analyses and these tests that most quartzites contain more or less calcareous clays, which serves for agglomerating in the manufacture of silica bricks. The quartzite grains, covered by the clay, remain solid at high temperatures. The grinding of this quartzite sets at liberty clay which, in the presence of silica and a small quantity of lime, forms a plastic mass which begins to vitrify and to contract from 1,250°, and produces a compact and tough mass which envelops the grains of quartzite and gives stability to the product.

There will accordingly be interest for the manufacturer of silica bricks, who uses quartzites, to analyse and investigate the quantity of clay contained in these quartzites and to use a high proportion of impalpable material in order to obtain a more compact product; if the quartzites are rich in clay and well ground the quantity of lime to be incorporated can be very much reduced.

In these products alumina plays the part of a flux: it is indispensable. If the rocks used in this manufacture do not contain free clay it will be necessary to add a small quantity proportional to the quantity of impalpable silica obtained by grinding. If the rock free from clay contains after grinding 20 per cent. of material passing the 200 sieve, 2 to 3 per cent. of aluminous clay and the proper quantity of lime can be added.

This mixture is necessary in the manufacture of silica products on the basis of flint or of quartz when these two latter varieties of rock are suitable for this manufacture. I will indicate further in what conditions they can be suitable to give well agglomerated products. Indeed, quartz contains ordinarily only an insignificant quantity of foreign matter; flint contains a little more; but, as flint has to be calcined before using it, the plastic quality of the foreign materials which it includes is destroyed by this calcination.

Physical Studies.

Physical studies of siliceous rocks permit observations on variations of shape, density, volume and porosity under the influence of elevated temperatures.

Bricks and pieces of silica destined for Martin furnaces should in the parts in contact with the hot gases resist a temperature of 1,700° without fusing, without the grains becoming disintegrated, without the plastic mass formed from the fine siliceous parts mixed with clay and lime becoming dislocated under the influence of excessive expansion of the more or less large grains of siliceous matter which enter into the composition of the products.

Heating at 1,710°.—In the physical study of siliceous rocks the first test consists in taking these rocks to the temperature at which the trial piece bends down, and letting them cool slowly. In practice samples are taken weighing about 100 grm., and they are brought in 4 or 5 hours to a temperature of 1,710°, kept at that for one hour, and then allowed to cool for 2 or 3 hours before coming out of the furnace. During this operation the siliceous rocks have taken their

maximum elongation. After this operation the siliceous rocks appear under various aspects, of which the principal are:—

1. They are melted; this is the case with rocks containing alkalies or an excess of alumina; these rocks are unsuitable for the manufacture of silica products.

2. They are not melted:—

A. Certain rocks have remained compact, have preserved their shapes, but present a few cracks. This is the case with quartzites, and of certain quartzose sandstones; they are suitable for the manufacture of silica bricks under conditions which I will indicate further on.

B. Rocks which resist at 1,600° fall into powder or into very friable grains at 1,700°; this is the case with a certain number of sandstones, of siliceous stones fit for millstones, etc. These materials are not suitable for the manufacture of silica products because of the friability of their grains at high temperature.

C. Quartz and quartzose rocks after heating to 1,710° are generally split into larger or smaller pieces, completely severed. Those which give compact and tough pieces of moderate size return to the category of materials suitable for the manufacture of silica bricks; those which give too small pieces should be left aside.

D. Flint breaks up uniformly into larger or smaller and more or less compact pieces. Those which produce large pieces can be suitable, *à priori*; those which divide into too small pieces must be discarded.

By this simple experiment of heating to 1,710° all the rocks which at this temperature remain neither compact nor tough are immediately eliminated. This method has been pointed out nowhere to my knowledge. Certain manufacturers introduce into the composition of their silica products rocks which, unknown to them, are friable at high temperatures; thus they make pieces which are not resistant, and which disintegrate spontaneously in metallurgical furnaces.

Siliceous rocks susceptible of being employed in the manufacture of silica products are therefore brought back to three categories: certain quartzites or quartzose sandstones, certain kinds of quartz, and flint, of which the trials indicated above rendered possible a first eliminatory choice.

Elongation (Expansion).—Siliceous rocks begin at 1,200° to undergo an expansion which increases by degrees up to 1,710°; in proportion as the fusion point is approached expansion ceases and even gives place to a slight contraction. I will pass over some accidental cases. During this expansion the nature of the silica is modified.

This expansion is accompanied by variation of density and porosity, so that the study of expansion should be accompanied by study of density and porosity, which are made on the same samples.

Certain quartzites heated to 1,710° take an expansion which exceeds 9·5 per cent. and is under 10 per cent. The Germans, in certain works, employ quartzites of this kind. Since the war a few French manufacturers make use of a quartzite of which the expansion at 1,710° is 9·8 per cent.; others make use of quartzites which take an expansion bordering on 15 per cent. There exist in France a great number of quartzite beds, the rocks of which expand in very variable proportions between the two limits of 9 to 15 per cent. Manufacturers of siliceous products will have the advantage of choosing the quartzites which take the weakest expansion in order to avoid exaggerated expansion of the bricks.

The measure of the expansion is made by means of a rule provided with a vernier; this operation is simple and within the reach of all.

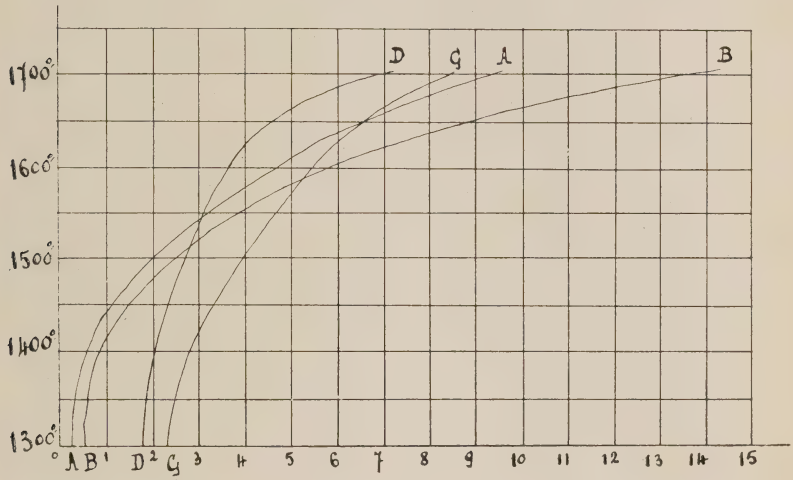
Density.—According as silicas expand their density diminishes. The apparent density is obtained by means of the hydrostatic balance by the academical process. The absolute density is obtained by the method of the small bottle operating on a known weight of the material in powder. Le Chatelier and Candlot's apparatus gives rapid and practical results.

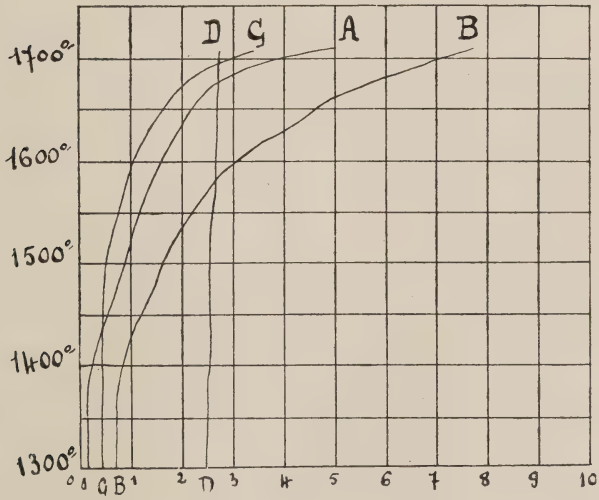
Porosity.—Under this name is signified in practice the ratio between the weight of water absorbed by the material and the weight of that material dry. The operation takes place in the following manner:—The material is dried at 100° and weighed; it is allowed to cool and immersed in water, where it remains 24 hours; it is withdrawn, wiped and weighed again, the increase in weight indicating the weight of water absorbed.

These three determinations, expansion, density, porosity, are made successively, with the same materials heated and maintained for an hour first at 1,400°, then at 1,560°, finally at 1,710°. The curves representing the different variations observed can then be traced.

By way of example I will show the expansion curves and the porosity curves of four varieties of silica in pieces which I have studied. *A.* Quartzite with weak expansion. *B.* Quartzite with great expansion. *C.* Quartz. *D.* Chalk Flint. The numbers on the verticals indicate temperatures in degrees Centigrade. The numbers on the horizontals indicate the percentages.

From these curves it is seen that the samples of flint and quartz are less expanded and have less porosity than the quartzites. It would appear, then, that they are better suited than quartzites for the manufacture of silica products. But





experience shows that it is nothing of the sort. Quartzites give better results because of the interposed clay which they contain and which constitutes an agglomerant.

Micrographic Studies.

Certain quartzites present at 1,710° an expansion under 10 per cent., others have an expansion bordering on 15 per cent. The reasons for these differences are not yet well understood, but they depend on the crystalline constitution of these rocks. When a natural quartzite is examined under the microscope the presence of small silica crystals locked into one another and surrounded by an amorphous sheath is ascertained. This latter is certainly argillaceous matter. After heating to a high temperature the silica has been transformed into cristobalite and into tridymite, its density has diminished and its volume has increased. At the same time, under the miscroscope, cracks are observed in the whole mass; it is possible that it may be the number and the dimensions of these clefts which provoke different expansions in the quartzites. Microscopic study will certainly permit the determination soon of the exact causes of variation in the expansion of siliceous rocks.

XXVI.—On the New Refractory and Abrasive Matter called Corindite.

Par Monsieur ALEXANDRE BIGOT, Docteur des Sciences, Consulting Engineer to the Ministry of Armaments and War Material Manufacturers.

IN 1914, a French engineer, Monsieur Noel Lecesne, who died lately from the effects of the absorption of poisonous gas, manufactured by him for National Defence purposes, took out a patent for a new process permitting the fusing of bauxite in a very economical manner.

In 1916, Monsieur Lecesne filed an application in England for Royal Letters Patent, which was subsequently accorded him.

In the course of the year 1916, Monsieur Lecesne, who was even then very ill, had recourse to me to finish the trials and essays already begun on those products which can be manufactured from bauxite fused by his process.

I will here briefly describe my studies and the industrial consequences resulting from them, for the question interests in the highest degree the metallurgic industries of the Allies.

Bauxite, very abundant in the South of France, may be summed in two categories: white and red—but, whatever their nature, their fusion is obtained in the same way by the Noel Lecesne process.

The composition of French bauxite is varied, it contains on an average 60 per cent. alumina, about 3 per cent. titanic oxide, and 14 per cent. constitution water. White bauxite contains a notable quantity of silica and a small quantity of iron oxide; good red bauxite contains from 2 per cent. to 3 per cent. silica, the remainder is iron oxide.

As an example, I give two analyses of bauxite:—

	White Bauxite	Red Bauxite
Alumina ...	59·20	60·10
Combined water ...	14·10	14·20
Titanic oxide ...	3·5	3·30
Silica	18·50	2·85
Iron oxide	4·70	21·55

The Lecesne process consists in heating in a cupola oven a mixture of bauxite and anthracite by blowing air into the lower part; before placing the matter in the cupola a fire has been made in the lower part. Under the simultaneous influence of the fire and the combustion gas the bauxite is reduced, aluminium carbide is formed, which, in the presence of surplus air, is transformed almost entirely into alumina; the heat developed by the reaction is such that the mass goes into fusion by successive layers—a special contrivance prevents the matter from adhering to the refractory matter composing the sides of the oven.

The operation terminated, the mass is cooled by means of the surplus air, and a vesicular fused block is found, in which an immense number of small alumina crystals will be seen disseminated in the solidified mass.

The products obtained have been subjected to analysis after having been freed from the metallic parts by means of a magnet.

	White Bauxite Fused	Red Bauxite Fused
Alumina	68·80 ...	69·25
Titanic oxide ...	3·85 ...	3·70
Silica	21·40 ...	3·00
Iron oxide	5·25 ...	23·35
Carbon	0·60 ...	0·50
Loss on ignition ...	0·10 ...	0·15

This fused bauxite has been designated by the name of "corindite," on account of the crystallized mass of corundum.

White fused bauxite is a very refractory substance.

Red fused bauxite resembles emery in its composition; it is a powerful abrasive substance.

1.—Refractory Products.

Fusing Point.—The point of fusion of the corindite prepared from white bauxite taken from the Var department is very high; a cone made from this corindite begins to partly melt at 1,950° C. It melts at a higher degree than the bauxite which served to make it. This anomaly is explained by the fact that the iron oxide which is found in the corindite has passed almost entirely into the ferrous state and a "spinel" Al_2O_3FeO is formed, resisting a very high temperature.

Binders.—The crushed corindite is mixed with refractory binders, finely pulverized, such as bauxite, kaolinic clay, etc.

Binding must be avoided with such bases as lime, magnesia, calcined dolomite, etc. . . . . which lower the fusing point of

the mixture. The corindite and its binder are suitably moistened and mechanically mixed; the mixture thus treated is employed as an ordinary refractory mixture for the manufacture of firebricks, by hand or by machine. Those made by hand, in a soft paste, show in drying a shrinkage of from 1 per cent. to 2 per cent.; those made by machinery do not shrink in drying.

Baking and Shrinkage—The dried bricks are baked between 1,350° and 1,400° C.; they undergo no shrinkage. Between 1,700° and 1,730° they lengthen by about 0·5 per cent. Above 1,750° they begin to undergo a shrinkage attaining 3 per cent. at 1,850°.

Porosity.—The porosity depends on the mechanical composition of the mixtures and on the compression, it varies from 9 per cent. to 12 per cent.

Resistance to wear.—This resistance is very great; the product is three and a half times more resisting to wear than good magnesia bricks. A lining to rotary cement kilns made of agglomerated corindite lasts twice as long as a lining made of bricks of non-fused bauxite.

Action of slag and scoria.—Refractory products based on fused bauxite are attacked by slag and scoria in the same way as refractory matter made from non-fused bauxite. The action of slag and scoria is being studied and is not yet completed.

It is now ascertained that corindite products possess three essential qualities:—

1.—Refractory power very high.

2.—Variation of volume almost nil up to 1,750° C.

3.—Very great resistance to wear.

Therefore the employment of these products will yield good results in rotary cement kilns, in gas and heavy oils ovens, in coke ovens, etc.

Following on these results an important French Society has been constituted for the working of the French patent; an Italian group has acquired a license for the Italian patent.

It would be of the greatest interest for the English refractory products industry to exploit the English patent.

There exist, effectively, in Ireland considerable deposits of white bauxite, relatively poor in alumina and up to the present useless. Fusing trials have been carried out on 500 kilogs. (half a ton) of this bauxite; the results were the same as with the French bauxite.

Bricks made from this fused Irish bauxite have been tried in England with success.

Nevertheless, as Irish bauxite is a little less rich in alumina than French bauxite, its refractory power is a little lower, but remains far superior to that of other argillaceous refractory matter in England.

Fused bauxite is therefore veritably a new product highly refractory; it is a commercial product on account of the abundance of raw material in France and in the United Kingdom, and also because of the cheapness of its manufacture.

2.—*Abrasives.*

Red bauxite, fused by the Lecesne process, furnishes abrasive matter of very good quality. The red bauxite suitable is that employed for the manufacture of pure alumina.

Red fused bauxite is of a composition approximating to that of emery. If the analysis given above is compared with that of Naxos emery, it will be found:—

	Fused Red Bauxite	Naxos Emery
Alumina	69·25 ...	69·46
Titanic oxide ...	3·70 ...	—
Silica	3·00 ...	2·41
Iron oxide	23·55 ...	19·08
Carbon	0·50 ...	—
Lime	— ...	2·81
Combined water ...	— ...	5·47

The percentage in alumina is sensibly the same; emery contains combined water, as also lime. Now the presence of lime lowers the fusing point of emery to about 1,600° C., whereas red fused bauxite can be carried to 1,700° without melting. It therefore results that with this corindite ceramic wheels of excellent quality can be manufactured at a temperature of 1,500° C., which is quite impossible with emery, which is too fusible.

Red fused bauxite is not as abrasive as natural or artificial corundum at 90—92 per cent. of alumina, since it only contains 70 per cent. of alumina, but it is superior to emery; it is suitable for the manufacture of special wheels, less hard than those of corundum, but which have numerous uses in the metal industry.

The manufacturing price of red fused bauxite is lower than that of white, red bauxite being very cheap.

At present the scarcity of abrasives is very great. In the Allied countries there is neither enough corundum nor enough emery, and it is of the highest importance to organize immediately the manufacture of abrasives based on red fused bauxite.

XXVII.—Native Supplies of Refractory Materials available in the Sheffield District.

By W. G. Fearnsides, M.A. (Cantab.), F.G.S., M.I.Min.E., etc.,

Sorby Professor of Geology in the University of Sheffield.

AMONG the various circumstances which have made Sheffield the metropolis of the steel industry and the chief naval armoury of the British Empire, and have enabled her to maintain her proud position as the world's chief producer of the finest grades of steel, there is no more important factor than the native mineral wealth of the coalfield area on the western edge of which the city has grown up. This great East Pennine or North Midland coalfield extends continuously from Leeds and Bradford in the north as far to the south as Nottingham, and eastwards from Sheffield, by Rotherham and Doncaster, almost to the Trent. From it come the vast quantities of the diverse special kinds of fuel which high-temperature metallurgical furnaces require. Within it or upon its immediate confines occur our supplies of refractory materials, some of which are of such reliable quality that they tolerate the difficult conditions which obtain in steel-melting and steel-refining furnaces, and by their very limitations have imposed the specifications which the world accepts as proper to the highest grades of steel.

It is the purpose of this present paper to offer to the Refractory Materials Section of The Ceramic Society a summary account of those local supplies of refractory materials which experience has proved to be of value in the industries of Sheffield, and in passing, to mention other possible sources of mineral raw materials which present knowledge leads one to expect may be of use in the future. The order in which the various sources of supply will be considered is that of their geological age, which, by reason of the grain (*i.e.*, the geological structure) of the Eastern Pennine country, roughly corresponds with a geographical progression across the district from south-west to north-east, in general parallel with the course of the

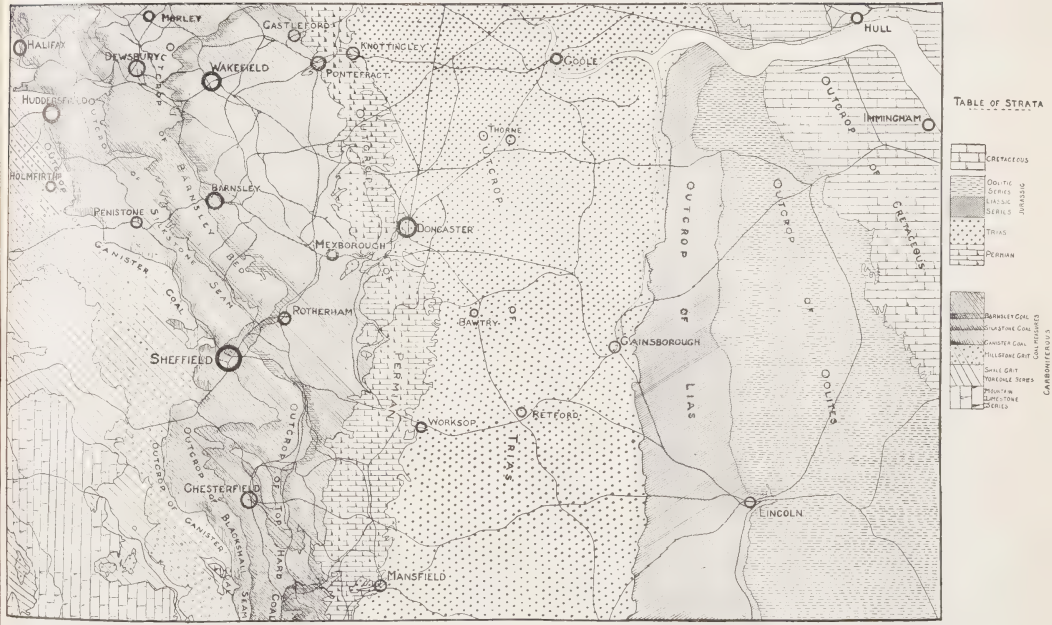
River Don. Those who are interested in the details of the distribution of the rock-beds mentioned, and wish to pursue the matter further, will find much useful information imprinted upon the 1 inch Geological Survey Ordnance maps, Old Series Sheet Nos. 81, 82, 87, 88, and New Series Sheet Nos. 100, 112, 113, 125, 126, and in the Geological Survey memoirs issued in association with those maps. Reference to a geological map of the South Pennine Coalfield area, on which the main lanes of road, railway, and other means of communication are shown (*e.g.*, Plate VII, Vol. LI of the Transactions of the Federated Institution of Mining Engineers, 1917), will in any case facilitate the comprehension of the geographical distribution of the sources of materials described.

The Carboniferous Limestone Series.

The oldest geological formation which comes to outcrop within the area accounted as forming part of the Sheffield district, is the Lower Carboniferous Limestone (Mountain Limestone) of Central Derbyshire, which outcrops also in the inliers of Ashover and Crich. At many localities on the outcrop of this formation, more particularly in Millers Dale, at Castleton, and at various places along the Buxton to Ashbourne railway, certain beds of this 2,000 feet thick limestone series are particularly pure; the lime which they yield when burnt is therefore a heat-resisting basic material of the most refractory class. By reason of the chemical activity of calcium oxide at high as well as low temperatures, however, the main purpose of the application of lime in Sheffield works, both where refractory materials are manufactured and where they are used, is not as a heat-resisting material but as a chemical reagent which combines with silica, clay and alumina, or with any other quasi-acid material, to form compounds which at high temperatures exist as relatively fusible bonds or slags.

Elsewhere in Derbyshire, and more particularly in localities where the products of Carboniferous volcanoes were injected or ejected among the limestone beds, thick beds and great masses of the limestone have been partially or wholly converted into dun stone or dolomite, which, if bulk analysis is any real criterion of the suitability of raw dolomite for the manufacture of "basic" shrunk dolomite, affords in Harboro' Rocks and others of the crags which flank the High Peak mineral railway in the region about Brassington, an immediately accessible reserve of material rich in magnesia and low in silica sufficient to supply the whole country's demands for "basic" for a century to come.

GEOLOGICAL SKETCH-MAP OF THE SHEFFIELD DISTRICT.



SCALE - 1 in. = 8 miles.

The Yoredale Shales and Shale Grit Series.

Because of the general remoteness from centres of industry of the heather and grass-clad moorlands which occupy the outcrop of these formations, the details of their lithological constitution have hardly been explored. Outcrops of more than one bed of crowstone of quality similar to the ganister (so-called) worked on Mow Cop in Staffordshire, and almost certainly of equivalent age, have been observed in the wild upland valleys of the Ashop, the Allport, and the reservoir region of the Upper Derwent, but are thin and too far from any railway to render their working probable.

The Millstone Grit Series.

By reason of their strength and thickness, the massive sandstones of this formation form high moorland "edges" or escarpments, and the constitution of the softer shale measures which occur between them is very imperfectly known. Crowstones of some value as a substitute for ganister are worked on a small scale in the Meltham district south-east of Huddersfield, and are known to outcrop across the moorlands to the west and south of Sheffield. Concerning the occurrence in the Pennine area of fireclays equivalent in age to the famous clays of Glenboig, Bonnybridge, Stevenston, and other districts in Western Scotland, little information is available. Occasional outcrops of highly aluminous clay beds have been noted in some of the ravines which traverse the moors to the north-east of Sheffield, and it should be worth while for local makers of high-class firebricks to have a systematic investigation made of all the various beds of "spavin" which are approachable at their outcrop between the Millstone Grit edges further to the north.

The Lower Coal Measures Series.

Of all the diverse geological formations which supply raw material for use in furnace construction in the Sheffield industries, none is held so important as the belt of measures which contains the Halifix Group of coals, and forms the lowest 500 feet of the 1,700 feet of Lower Coal Measures which intervene between the Rough Rock or topmost sandstone of the Millstone Grit Series and the Silkstone Seam of coal.

As characteristic of the Don Valley development of these Halifax or Ganister Measures, the succession proved in the workings of the Silica Firebrick Company's mines in the

neighbourhood of Oughtibridge, may be given in tabular form as follows:—

Coal	0′ 10″	
Fireclay	4′	
Wharncliffe Rock	12′	
Shale with Stone Bands	120′	
Halifax Hard Bed Band Coal		Not found
White Car Clay		Not found
Loxley Edge Rock	20′	
Marine Shales	24′	
Halifax Hard Bed or Ganister Coal		Variable, average about 1′ 10″
Sheffield Ganister		Variable, average about 2′ 6″
Ganister Under-bed Clay	5′	
Shale	36′	
Hard Bind (Firestone)	6′	
Coal Smut	0′ 3″	
The Bastard Ganister		Variable, average about 1′ 6″
Fireclay	5′	
Siliceous Fireclay (Firestone)	3′	
Shale	6′	
Middle Band or Clay Coal	0′ 10″	
Fireclay	5′	
Middle Rock (Firestone)	22′	
Shale	17′	
Halifax Soft Bed or Coking Coal	0′ 11″	
Fireclay	4′ 6″	
Crawshaw Flagstones	60′	
Shale	90′	
Coal Smut	0′ 3″	
Pot Clay	4′ 6″	
Earthy Stone Bind	3′	
Millstone Grit		
	450′ - 500′	

Nowhere, so far as I have information, has the whole of this succession of the Ganister Measures been traversed in any single shaft or bore-hole, and experience has taught me that computations of thickness made among them by the comparison of overlapping sections at localities no more than a mile or two apart are apt to give very discordant results. Of the individual rock groups in the series tabulated, only the Halifax Hard Bed Coal, with its associated seat-earth of ganister and its roof of shell-bearing marine shales, is continuous and recognisable along the whole length of the outcrop of the Lower Coal Measures of the South Pennine area. Of the other beds the coals are the most persistent, but are distinctly variable, and the shales, and especially the massive sandstones which are built up of overlapping lenticles, attain their maximum thickness (which often amounts to fully 100 feet) and tail out to nothing within the limits of the area reviewed. Despite, however, the lens-like character of these more rapidly accumulated constituent members of the Halifax

or Ganister Group, the series as a whole possesses evident continuity and maintains a fairly uniform average thickness, so that, taking the roof shales of the Ganister Coal as a datum-line from which to measure, it is not difficult anywhere in the Yorkshire and Derbyshire district to discover and recognise the exact geological position of any individual bed.

Within a score of miles of the city of Sheffield, the dozen different beds indicated by italics in the table given above, have in the past been tried and proved to have a certain economic value as refractory materials, but at the present time the main efforts of the silica brick manufacturers are concentrated upon the development of their workings in the Halifax Hard Bed, whilst those of the makers of fireclay goods are almost entirely confined to the exploitation of the pot-clay bed in the vicinity of Sheffield, and to the White Car clay (*i.e.*, the Halifax Hard Bed band clay) in the district further to the north.

The Pot-clay.—Quite at the base of the Lower Coal Measure series and separated from the topmost grit of the Millstone Grit series by less than ten feet of measures, which are sometimes sandy binds and sometimes nodular and lumpy mudstones, is the Stannington bed of black fireclay or pot-clay (generally spoken of in steel works as "local clay"), a material which has been used for the making of the pots or crucibles used in the Huntsman process of crucible steel making for over 150 years. As a clay for crucible making, the pot-clay is at its best where, as near its outcrop, it has been exposed to the action of percolating water for a period which, measured historically, must have been very long. It is exploited under the best geological conditions in shallow workings driven to the rise under the moorlands on the south side of the Loxley Valley, in which valley it attains its maximum thickness of over 10 feet. As near its outcrop it is well weathered, it affords a supply of clay which is both plastic and particularly refractory, but where mined under a considerable thickness of impervious cover it is found over-rich in carbonaceous material and generally contains scattered large or small nodules full of iron sulphide, which, when the clay is heated towards its vitrifying temperature, reacts with the free silica always present and produces bloating. Apart from its historic use for crucible making, the Loxley clay is much in demand for the making of "stoppers and nozzles," "sleeves and runners," and various other shaped articles used as insulators to control the rate of cooling of ingots, for which purposes the ability of properly burned articles made of this material to survive the quick temperature change involved when they are brought

into contact with molten steel makes the pot-clay exceedingly valuable to the staple industries of Sheffield.

Away from the Loxley Valley the pot-clay bed is not so thick, and geological conditions have not favoured the complete leaching out of its soluble or oxidizible impurities. South of the Rivelin I have no knowledge of commercial success having attended any of the various attempts which have been made to work it; but northwards from Bradfield, along the Don Valley to Stocksbridge, it is of moderate thickness and of quality suitable for mixing with silica rock in the manufacture of ground ganister. About Deepcar it is a clay carrying a high percentage of alumina, and is used for the manufacture of refractory firebricks such as are needed for the building up of steel furnace doors.

The seat-earth of the Coking Coal or Halifax Soft Bed, though in appearance very like a number of famous fireclays, contains in the district between Sheffield and Stocksbridge many siliceous and ferruginous nodules, and is generally too rich in alkalies to be of much interest as a refractory material in steel works practice. When fully weathered it breaks down into a clay which has considerable plasticity and may have some economic value for the making of sanitary pipes. The lower of the two beds of ganister which are being worked in the Ambergate district of Derbyshire occurs not far from this bed, but is not associated with more than a very few inches of coal.

The Middle Rock is one of the composite lenticles of sandstone which are of frequent occurrence and form an important part of the total bulk of the rocks of the Lower Coal Measures of the Yorkshire and Derbyshire district. In its place in the succession (above the Coking Coal and well below the main bed of ganister) its outcrop happens to cross the district where originally the cutlers set up their water-driven grinderies, and, when quarried and built into the walls of their small furnaces, proved its worth as a refractory material and so gained a reputation as a firestone. In more recent times at certain localities along the Don Valley between Sheffield and Deepcar the Middle Rock has been quarried and used as a cheaper substitute for mined ganister. In certain of the quarries in this area the sandstone is particularly free from grains of felspar, and when it is finer grained and the grains are more angular than usual the rock is so hard and compact that it can be used with advantage in admixture with true ganister for the making of certain grades of silica brick. In general, the beds which make up the Middle Rock contain a small proportion of ochre or (if unweathered) carbonate of

iron, to the presence of which the rock, when used as a firestone, owes its fritting property.

The Clay Coal or Middle Band Fireclay.—In the immediate vicinity of Sheffield neither the Clay Coal nor its under-clay is thick enough to have attracted much attention. North-westwards along the Don Valley the clay, which is rich in alumina, becomes thicker and of a quality useful both for firebrick-making and as a binding clay in admixture with ground ganister. Between Stocksbridge and Hazelhead, where the Clay Coal is thick enough to be workable, its under-clay is reputed to be "one of the purest clays in the district," and about four feet thick.

The Bastard Ganister.—Over a small area which extends from Middlewood on the outskirts of the city as far as Deepcar, and only a few feet above the roof of the Halifax Middle Bed or Clay Coal, there occurs a bed of crowstone, the bastard ganister, associated with a thick bed of siliceous fireclay of variable composition. This bed of crowstone or bastard ganister is rarely more than 18 inches thick, but the circumstance that it is overlain by a coal smut, in turn succeeded by a slabby sandstone, which in shallow mining affords a permanent roof, gives it a certain interest and potential commercial value, and in the future, when a market shall have been developed for the coarse-grained fireclay (containing over 90 per cent. SiO_2) which underlies the ganister, that value is likely to increase. Hitherto only the crowstone itself has found a market, and it is an interesting comment upon the influence which roof conditions have upon the cost of mining, that in one particular mine, where the average thickness of the bastard is no more than 1 ft. to 1 ft. 4 in., it can be brought to bank more cheaply than the Halifax Hard Bed ganister only 50 feet higher in the series which is associated with 1 ft. to 1 ft. 10 in. of coal and has itself an average thickness of over 2 ft. to 2 ft. 6 in.

The beds of the firestone which about Oughtibridge overlie the bastard ganister coal smut are finer in grain, but otherwise quite similar to the Middle Rock. This firestone and the bastard ganister and its underlying fireclay are worked together by opencasting in the neighbourhood of Worrall and Wadsley close to Sheffield, and provide raw material for the making of liner blocks used in Bessemer and other types of pneumatic steel converters.

South of the city of Sheffield the group of measures including the Clay Coal and the Bastard Ganister Bed of the Don Valley region have not been identified with precision, but, in the opinion of the writer, the place in the geological succession of the so-called "thick" coal of the moorland district

traversed by the Dore—Grindleford Tunnel, cannot be far from this horizon. At the Strawberry Lea and Moor Edge mines, this thick coal has for its seat-earth a bed of pure and very fine-grained ganister, the thickness of which averages about 2 feet, but varies from point to point even more rapidly than does the thickness of the better-known ganister found in association with the Halifax Hard Bed. The bed of highly-siliceous "curly" or "gressle" clay which underlies this ganister, and in some areas almost replaces it, also has valuable properties as a refractory material.

The Halifax Hard Bed or Sheffield Ganister. For over a century the seat-earth of the Halifax Hard Bed Coal has been recognised by dwellers in the Don Valley as affording the toughest, hardest, and most compact rock in the whole countryside. In the old days its outcrop was extensively quarried for road-stone, and it was as road-scrapings that those who had "crucible-holes" for steel making by the Huntsman process, learnt to apply it, instead of fireclay, to the linings of them, and from the time when steel making in large Bessemer vessels or open hearth furnaces became the standard practice, Hard Bed ganister, as the most reliable of all known refractory materials belonging to the "acid" class, has been in great demand. Fortunately for the steel making industries of Sheffield, the Halifax Hard Bed or Ganister Coal is persistent across the Sheffield district, and though both the quality and the thickness of the ganister bed vary somewhat irregularly, the average thickness is greater, the average percentage of fluxing impurities less, and the average size of the quartz-grains smaller, than in any other area. Consequently, since 1840, when the Halifax Hard Bed ganister was first quarried for use as a refractory material, almost the whole of the outcrop has been dug into, and the best of the ganister which was immediately accessible and cheaply got has either been consumed or, by unsystematic mining, rendered water-logged, and by the breaking in of the roof of old workings made difficult to approach.

In consequence of the open-jointed character of the massive sandstone rock beds which form the main mass of the Lower Coal Measures above the horizon of the Halifax Hard Bed, and of the persistent dip of the measures towards the centre of the coalfield basin, workings in which the Hard Bed ganister has been followed down-dip far in from the outcrop generally collect the water seepage in considerable volume. Under such circumstances it becomes necessary to secure facilities for the draining of the mines by the driving of soughs or adits, or by the installation of powerful pumping machinery,

and when the mineral has to be wrought below the level of the neighbouring streams and rivers it becomes a question of local working conditions, and the cost of transporting the material won to the works of the user, whether such mines can continue to compete successfully against other less fully developed undertakings which are exploiting outcrop measures. In the immediate neighbourhood of Sheffield the available reserves of outcrop ganister are so far exhausted that during the war its price at pit-mouth has been controlled at 15/- per ton, and 90 per cent. of the total production is obtained by mining.

In Derbyshire the coal seam known in Yorkshire as the Halifax Hard Bed goes by the name of Alton Coal, and has in several districts a seat-earth of good class ganister, elsewhere replaced by mealy sandstone or by a nodular, siliceous, and often pyrites-bearing fireclay, and varying rapidly both in thickness and quality from place to place. In recent times, ganister from outcrop workings of the seat-earth of the Alton Coal has been coming into Sheffield from Bullbridge, near Ambergate, Alton near Clay Cross, and in considerable quantity from Holymoorside near Chesterfield. Immediately to the north of the Dore and Grindleford Tunnel the Halifax Hard Bed Coal takes on its familiar Don Valley qualities, and the ganister beneath is found to be excellent in thickness and condition. Under Dore Moor and about Dore village the coal is thicker than average, and much of it was long since taken by the bell-pit workers, who left the ganister beneath it undisturbed. From Beauchief, by Millhouses, Ecclesall, Ranmoor and Crookes as far as Walkley, the coal bed continues to be of greater value than the ganister, and by old bell-pits and adits its outcrop can be traced through the suburban gardens into the Sheffield city area, where increase of the rateable value of the surface has cut short any tendency towards further exploitation of any mineral which may be present underground. North of the Rivelin Valley the thickness of the ganister averages 2 ft. 6 in., and under the ridges which separate the Rivelin from the Loxley and the Loxley from the main Don Valleys the ganister is particularly fine in texture and of the very best composition. Being advantageously situated well above the water level of the rivers and having easy facilities for the delivery of the produce of the mines into Sheffield works, this area has long been very actively developed, and those who are concerned with the exploitation of the Halifax Hard Bed beneath it must be contemplating with regret the fast approaching exhaustion of their mineral. On the east side of the Don through Beely Wood and below Wharncliffe

Crags, as far as Deepcar Station, the outcrop of the Halifax Hard Bed Coal is unbroken, and the average thickness of the ganister increases without any serious deterioration of quality. At the Beely Wood Mine, near Oughtibridge, the ganister has been followed down dip some 500 yards into the hill, and in the Wharncliffe Mine, close to Deepcar Station, it has been found worth while to extend the main drift over 1,000 yards in from the outcrop, and mining of the ganister is now being undertaken below sea-level. At certain places in Beely Wood and also in Wharncliffe I have seen and measured the ganister bed where it was over 6 feet thick, but these were exceptional places, and in general in this Don Valley district the average thickness appears to be about 3 feet. Wherever the ganister is over-thick the constituent quartz particles are found in rounded condition, and there is also a tendency for them to increase in size, so that by deterioration of its quality the bed as a whole loses more than it gains from the abundance of the yield.

Associated with the Hard Bed ganister about Oughtibridge and Deepcar there is generally an underbed of bastard ganister which, because it "falls" when exposed to weather and is comparatively easy to drill, is spoken of by the miners as "clay." This bed is often over 4 ft. in thickness, and although it contains a considerable proportion of some micaceous material, it is quite refractory at temperatures up to 1,250° C. When blocks made from it, with a small proportion of added lime for bond, are burnt in a kiln along with silica bricks, they vitrify and become almost as compact as porcelain, keeping their bulk or very slightly expanding in the process. It would seem that such material, which could be mined very cheaply along with the ganister, has a great future as a suitable raw material for the manufacture of coke-oven bricks.

Beyond Deepcar the outcrop of the Halifax Bed ganister follows the left bank of the Little Don as far as Langsett, whence north-westwards it takes a rather irregular course across the moorland by Bullhouse, Hazelhead, Hepworth and Brockholes Junction to Huddersfield and so by Elland to Halifax. Between Deepcar and Stocksbridge, as also in the narrow mile-long outlier which tops the Allmans Hill south of the Little Don Valley, the purity and fine texture of the ganister is maintained with a gradual diminution of its average thickness as it passes to the westward. Some of the ganister from certain areas within the Little Don watershed is peculiar in that the rock as mined contains an appreciable proportion of calcite, which takes the place of the usual secondary silica as cement between the grains of quartz. North-westwards

from Stocksbridge, although the Halifax Hard Bed Coal continues with little change and on the average improves in quality, the ganister beneath it is found mingled with clay and very patchy in its development, and only here and there, where it averages perhaps a foot in thickness, is it pure enough to be worth working except along the outcrop. Where it is absent its place is taken by a bed of hard siliceous clay not unlike the ganister under-bed mentioned as occurring in the Don Valley, but richer in alumina and often almost free from alkalies. Where, as to the north of Huddersfield and about Elland, this fireclay is free from nodules of pyrites, or where the iron nodules present are large enough to be sorted out by hand, it has very valuable refractory properties, and is used for the making of glass pots and furnace sieges. In several of the workings in this northern district the clay worked contains a comparatively high percentage of silica, and the small shrinkage which goods made from it undergo when in use has given it a high reputation. Considerable quantities of firebricks made from the Halifax Hard Bed fireclay in the West Yorkshire area find their market, for furnace construction, in the Sheffield district.

The White Car or Halifax Hard Bed Band Clay.—Though the measures associated with the Halifax 40-yard Band Coal are as well represented in the Sheffield as in the Halifax district, the coal itself is so thin that it has not tempted exploitation, and in the district close to Sheffield the quality of its earth-seat has hardly been explored. In more northerly districts, as about Hipperholme, not far from Halifax, this seat-earth is a ten-foot-thick bed of fat and highly aluminous fireclay (containing up to 40 per cent. of Al_2O_3) which, despite its rather high content of iron oxide, being almost free from alkalies, affords a supply of the most refractory fireclay yet discovered in this East Pennine coalfield. The roof shales above the coal seam are also fairly free from alkalies, and in the Huddersfield district yield a somewhat coarse-grained, mixed clay and silica material which is suitable for use as saggar clay. Along the valley of the Little Don the White Car clay belonging to this horizon varies between 2 ft. and 4 ft. 6 in. in thickness, and is not so rich in alumina as its Halifax equivalent. It is, however, equally free from fluxing impurities, and, being easy to work and handle, is in demand for the making of fireclay shapes, which when burnt keep their form and fit accurately together. Blocks made from it have the property of standing at temperatures in the neighbourhood of 1,000° C. for very long periods without undergoing any appreciable volume change. The saggar clay which in this

district overlies the Hard Bed Band Coal is not so free from alkalies, but is useful because, when burnt in the kiln along with firebricks, blocks made from it become completely vitrified and develop acid-resisting properties without suffering any change of form.

Between Deepcar and Oughtibridge the White Car clay rests directly upon the thick Loxley Edge rock and is said to be very "stony" and spoiled with ironstone nodules. South of Sheffield, where the Loxley Edge rock is found considerably reduced in thickness, the character of the clay bed is also changed, and the Ganister Rider Bed, which was formerly worked about Millhouses, Beauchief, Dore and Totley, replaces its upper part and rests upon a clay under-bed which, though white and free from iron, is so little refractory that it is in request only for the making of stoneware jars and pots. The quality of the Rider Ganister at its outcrop is excellent, but its thickness, which averages no more than a foot, renders the mining of it unremunerative.

The Middle Coal Measures Series.—Concerning the refractory qualities of the various beds of fireclay, clunch or spavin shown by the records of colliery shaft sections through the upper part of the Lower Coal Measures and the Middle Coal Measures of the coalfield as occurring at least as frequently among the Higher Coal Measures[1] as among the Halifax Group, little information is available. However, the circumstance that the only locally-made bricks, other than those manufactured from the Halifax Measures, which are acceptable as firebricks among Sheffield furnace builders, have their origin in the seat-earth of the Better Bed Coal (a local seam which occurs some 200 yards above the Halifax Hard Bed in the district between Halifax and Leeds), inclines one to the opinion that most of the underclays associated with the coals of that series are inconstant in composition and often contain an over-large proportion of minerals which act as flux. Whether this general condemnation of the fireclays occurring in association with the coal seams as no better than second class is applicable over the whole coalfield, is a matter which only future systematic chemical survey can decide, but from the co-ordination of analyses of the occasional samples of under-clays sent to this department from collieries in the neighbourhood of Sheffield, I have little expectation that the seat-earth of any coal within the 700 yards belt of thick coal-bearing measures which intervene between the Whin Moor and the Shafton Coals of South Yorkshire is likely to have superlatively good refractory qualities.

1 In the record of the 304 changes of character in the strata passed through in sinking the No. 2 Pit at Maltby 820 yards deep to the Barnsley Coal, the word "clunch" (which is the sinker's ual description of fireclay) occurs 81 times.

Preliminary examination of certain beds of non-plastic "bat" or oil-shale, which are sometimes found associated with thin beds of cannel but have no well-recognised relationship to the workable seams of coal, has shown that they contain a high percentage of alumina, and it would therefore seem likely that such of them as are sufficiently free from alkalies may be of interest as a possible home supply to replace imported Swedish or French chamotte.

Towards the top of the highest part of the Coal Measure Series which is exposed in the Yorkshire and Derbyshire district, the characteristic colour of the measures changes from blue-black or blue-grey to variable paler shades of grey, green or red. In the 300 yards (or more) of measures which separate these Upper or Transitional Coal Measures from the thick coal-bearing series, are numerous beds of sediment, which in their chemical and physical properties are exactly similar to the non-calcareous rock beds known in the Potteries district of Staffordshire as "marl," and in this district described by those in charge of the sinking of colliery shafts as spavin or clunch. Owing to the scarcity of surface exposures in the coalfield area east of the line Badsworth, Hemsworth, Grimesthorpe, Hickleton, Conisborough, Wickersley and Dinnington in Yorkshire, as also in the other much smaller Derbyshire area south of Bolsover, where the outcrop of this rock series forms the surface of the ground, little is known as to what economic value clunch may possess; but from laboratory experiments carried out to determine the refractory character of particular samples collected at a shaft-sinking in the concealed coalfield area, I am convinced that certain beds above the Mansfield Marine Band series have a composition admirably suitable for the making of coke-oven bricks.

The Permian or Magnesian Limestone Formation.

Resting unconformably across the denuded edges of the coal measures of the East Pennine coalfield, and separated from all of them by a considerable interval in geological time, the outcrop of the magnesian limestone forms a continuous escarpment ranging north—south and facing west from Pontefract by Doncaster to Mansfield across the Sheffield district. At the base of the Permian, unconsolidated sands fill up hollows worn in the pre-Permian land surface and occur in discontinuous patches along the base of the escarpment. Though these Permian sands are not sufficiently pure to deserve in these days the name of refractory materials, in times past

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c.f. Stobbs, this Journal, Vol. XVI, p. 108.

they supplied a great deal of the moulding sand used in local foundries, and instances might be quoted of the original sites of works, where the greater steel industry has now developed, being determined for convenient access to particular outcrops of Lower Permian sands. The overlying marl slate is of no interest as a source of refractory materials.

While the importance to Sheffield industry of the basal Permian sands has been declining, that of the beds of pure dolomite rock which form quite an appreciable fraction of the Lower Magnesian Limestone Formation over a wide area east of Sheffield has been tremendously increased, and at the present time more than one-third of the shrunk dolomite (*i.e.*, the refractory material generally known as "basic") manufactured in this country is made from the upper beds of the Lower Permian Limestone, worked by open-casting from a single quarry at Steetly, near Worksop, within 15 miles of the city of Sheffield. Along the whole length of the outcrop of the Magnesian Limestone formation in South Yorkshire and Nottinghamshire there is no lack of rock the bulk composition of which shows it to contain well over 90 per cent. of the theoretical equi-molecular mixture of the carbonates of lime and magnesia. At Steetly the quarry-face worked is over 20 feet in height, and about half of all the rock moved goes forward to the cupolas. Analyses of various samples of the rock as quarried show that it contains more than 95 per cent. of dolomite, and that excess of carbonate of lime is the chief (almost the only) impurity present. The residue of siliceous or aluminous clay remaining when Steetly dolomite is dissolved in dilute acid does not in general exceed 1·5 per cent. A belt of magnesian limestone measures yielding dolomite as free from fluxing impurities as that quarried at Steetly has been traced along a continuous 25-mile-long outcrop from Mansfield Woodhouse in the south by Langwith, Steetly, Maltby, and Warmsworth as far to the north as Brodsworth, and there is therefore no possibility that the now rapidly developing basic-steel making industry need ever go short of basic refractory linings for vessels used in the process of phosphorus removal, by reason of the failure of home supplies of dolomite. It is probable that the crystalline structure and general physical conditions of the dolomite rock as sent to the cupolas is a factor at least as important as chemical composition in determining the economic success of the Steetly process of manufacture of shrunk dolomite.

The Middle Permian Marls and the Upper Permian Limestone as developed in the region east of Sheffield are rocks

of very mixed composition and are of no importance to makers or users of refractory materials.

The Triassic Formation.

To the eastward of the magnesian limestone escarpment the outcrop of beds generally referred to as the Trias forms the Nottinghamshire and Yorkshire extension of the Midland Plain. Where, as about Doncaster, this lowland plain is nearest to Sheffield, most of the outcrop of the Trias is deeply buried beneath glacial drift or by alluvium deposited by the rivers in recent times, but occasional areas of harder rock stand up as islands and provide supplies of red sand-rock which only requires crushing between light rolls or in a pan-mill to make it ready and suitable for use as iron moulding sand. Wherever the outcrop of these lower variegated sands of the Lower Bunter series is crossed by railways which give convenient access to industrial districts, they are being worked on a very extensive scale, and the produce from sand-pits now in course of active exploitation at Mansfield, Warsop, Worksop, Doncaster and Heck, finds a ready market at foundries in areas outside, as well as inside, the East Pennine Coalfield district.

Above the lower variegated sandstone or moulding sand series follow the pebble beds of the Middle Bunter, whose (agriculturally) infertile outcrop determines the location of the Dukeries. The majority of the pebbles so abundantly concentrated in the pebble beds of this formation are hard and compact quartzites derived from the destruction of steep mountain ridges of Lower Palæozoic (Cambrian and Ordovician) rocks which at that time outcropped in the English Midlands. If, by some automatic process, the minority of fusible calcareous and igneous rock pebbles which accompany the quartzite pebbles could be discarded, the extensive outcrop of the Bunter pebble beds would provide a vast reserve of this highly siliceous (acid) refractory material.

The sands, sandstones, waterstones and marls which form the main mass of the Triassic Formation above the horizon of the Bunter pebble beds have in general a very complex mineral constitution, and none of them have yet been proved useful as a source of supply of refractory materials, though possibly certain of the marl beds which occur where the red Keuper rocks pass up into the dark shales of the Rhætic series and have been bleached might be worthy of trial.

The Jurassic Formation.

Concerning the chemical character of the shaly rocks, which, with interstratified cement-stone, marlstone and iron-

stone, make up the Liassic Series, little information is available, and there is no reason to expect that beds of useful refractory materials occur among them.

In many respects the Middle Jurassic Estuarine Series, which succeeds the Lias, and in Yorkshire and North Lincolnshire takes the place of the marine Oolitic Series of English areas further to the south, is a replica on a smaller scale of the Coal Measures. It is therefore not surprising that sand-rocks having refractory properties very like those of ganister, and mudstones sufficiently free from alkalies to be useful as fireclays, have been found among them. The localities (Danby and Castleton in Yorkshire, and Stamford in Lincolnshire) where these Middle Jurassic rocks are being worked for refractory materials, although within a fifty-mile radius of this city, are so situated that their products do not compete with the nearer coalfield sources, but rather serve markets outside the Sheffield district. Certain unconsolidated sands which form the topmost member of the Upper Estuarine Series are used in considerable quantities in admixture with other sands as the refractory basis of some of the most successful of British steel-foundry moulding sands. Sand-pits at Huttons Ambo on the North-Eastern (York to Malton) Railway, and South Cave on the Hull and Barnsley line, opened in rocks belonging to this geological horizon, are at the present time being actively worked to supply sand free from fluxing impurities to many Sheffield steel works. I have no knowledge of any Yorkshire or Lincolnshire occurrences of refractory materials among the Upper Jurassic rocks.

The Cretaceous Formation.

Though under pre-war conditions the cost of bringing sand from Bedfordshire to Sheffield steel works was so much higher than the price of sea-borne quartz sand brought as ballast from the Belgian Campine by coal-boats trading between the Humber and the Rhine, that the equally pure sands obtainable from the Lower Greensand Series of Leighton Buzzard were hardly ever used, in war-time it would have gone hard with many Sheffield industries if these home supplies of "hearth sand" had not been available for the hearths and banks of acid Siemens furnaces. Now both Leighton Buzzard sand and sand from the Kings Lynn district are used in considerable quantities, either alone for "core" sand or to bring up the silica percentage and improve the refractory qualities of other steel moulding sand mixtures.

The flints which occur abundantly as discontinuous nodules or layers among the Middle and Upper Chalk formations

(Upper Cretaceous Series) consist of a partially hydrated and non-crystalline form of silica, and, when freed from their chalky matrix and calcined, afford an acid refractory material which, when heated alone, remains unmelted at very high temperatures. Unfortunately, so far, no generally applicable and cheap process of binding particles of calcined flints into satisfactory bricks or blocks has been discovered, and the use of flint as a refractory material is limited to its employment in the pottery trades for raising the average silica percentage and for reducing the contraction undergone by "pottery bodies" under fire. If flint should be required for refractory purposes, the Wolds of Yorkshire and Lincolnshire could supply an almost unlimited amount, but up to the present for the purposes of the pottery industries it has been found cheaper to collect it by hand-picking among the pebbles of the modern sea-beach than to attempt to free newly quarried flint beds from their adherent chalk.

The Tertiary Formations.

No rocks of proved Tertiary age have been recognised as occurring in the Sheffield district, and now that sea-borne supplies of sand from the Continent and Southern England to steel and iron foundries are only available under very exceptional circumstances and in small amount, Tertiary rocks are hardly ever seen in Sheffield works. Under pre-war conditions Eocene sands from Erith and Charlton on the Thames Estuary, Miocene sands from the district south-east of Paris, Pliocene sands from near Charleroi in Belgium and from St. Erth in Cornwall, were imported to supply a green-sand moulding material which was sufficiently refractory to meet the difficult conditions which obtain in foundries where hot-run steel castings are being made.

Belonging to some intermediate epoch of the long period which has elapsed since the formation of the Trias, and earlier than the Pleistocene (Quaternary) Glacial period, and therefore having some claim to be considered along with Tertiary rocks, are the sands, clays and pebble beds which occur in occasional hollows or fallen-in caverns in the High Peak district of Derbyshire, having escaped the general denudation because they lie below the average plateau-level of the Mountain Limestone. During visits to the scattered pits or quarries in the High Peak district where these alkali- and lime-free refractory materials are being worked, the writer has arrived at the opinion that they are all foundered fragments of a sheet of Triassic sediment which was once continuous over the whole region, and rested unconformably on the Carboniferous Limestone rocks. It

would appear that the very evident steeply-dipping bedding planes, which are in general roughly parallel to the clean-cut walls of limestone which bound the deposits, were originally the horizontal bedding planes of the Bunter, Keuper or Rhætic beds; and it seems reasonable to suppose that the irregularities of their arrangement are due to the frequent if intermittent readjustments under gravity which took place *pari passu* with the dissolution in underground waters of the limestone masses which were originally their support. Concerning the nature of the chemical or geological process by which these Bunter pebble beds, Bunter or Keuper sandstones, Keuper and Rhætic marls and shales have been deprived of all their iron, calcium, magnesium, sodium, and potassium salts (in such a way that though the rocks maintain their particular textural and structural arrangements, yet mineralogically only simple mixtures of quartz with some hydrated form of silicate of alumina in varying proportions remain), nothing is definitely known. A rich reward should be the portion of anyone who is able to show those who are trying to make good-class refactory goods from sandstones or clays containing like impurities how commercially they may bring about a similar change. Open workings in the vicinity of Parsley Hay, Fryden, Brassington, Parwich and Alsop-en-le-Dale, all within twenty miles of Sheffield, are now being worked, some of them to a depth of over 50 feet, to supply these High Peak "silica clays" for the making of high temperature settings and linings; but, partly because of their geographical remoteness from the Sheffield industrial area and partly because the texture of the products makes them unsuitable for employment in furnaces where steel-melting temperatures are required, most of these products find their markets in other districts.

Glacial and Post-Glacial Drift Deposits.

Though the geological conditions which have prevailed over all the British area since the beginning of the Glacial period have favoured the mingling of rocks of very diverse composition in the jumbled terrestrial deposits known as Drift, a few examples might be cited where mechanical, as distinct from chemical, processes of selection have brought about the segregation of surviving fragments of a single and therefore on occasion a refractory kind of rock. The composition of the materials, which form the maze of fluvio-glacial sand and gravel ridges in the lowland district between Doncaster and Retford, and are now being exploited about Bawtry as a source of supply of siliceous refractory materials, is a typical example of the case in point. About Bawtry fully 90 per cent.

of the pebbles, which occur more or less scattered through a matrix of sharp siliceous sand, have been derived from the denudation of Bunter pebble beds probably from the Dukeries and Sherwood Forest district, and have survived the journey with little change. During this latest process of their natural selection most of the softer felspathic sandstones and igneous rocks present as pebbles in the Bunter have either been destroyed or considerably reduced in size, and bulk samples of Bawtry gravel which has been retained on a screen with $1\frac{1}{2}$ in. holes show well over 94 per cent. of SiO_2, alumina and iron oxides being the most abundant impurities whose presence is disclosed by chemical analysis. By hand-picking to discard the occasional igneous rocks, slaty rocks, cherty limestones and the more mealy of the Carboniferous and Jurassic sandstones which have come into the pebbly deposits by another route, the average silica percentage in the residuum can be raised to 96 or even 97 per cent., and in the material used for silica brick making is maintained above 95 per cent. Certain of the beds of sharp sand which underlie or alternate with the fluvio-glacial pebble beds quarried for silica brick making at Bawtry, and for other purposes at Doncaster and Barnby Dun, are also fairly high in silica (95 per cent. SiO_2), and have found an occasional market at some Sheffield steel foundries as an emergency substitute for the purer and more reliable siliceous sands which have to be rail-borne from the Kings Lynn and Leighton Buzzard districts. Superficial Drift deposits resembling those of Bawtry cover a very considerable area on the borders of South Yorkshire and Nottinghamshire, but the proportion of pebbles containing an over-large percentage of fluxing impurities varies so rapidly and irregularly from place to place that no estimate can be made of the economic possibilities presented by the deposit as a whole.

Reviewing now the information assembled in the foregoing pages, it is evident that in its possession of ample reserves of those kinds of mineral raw material which are required for the construction and maintenance of all kinds of high temperature furnaces used in the making and working of iron and steel, the Sheffield district is particularly fortunate, especially in the local development of the beds of refractory mineral material which form an important fraction of the lower part (the Halifax Group) of the Lower Coal Measures series. Towards the top of this Halifax Group of measures occurs the famous Sheffield (Don Valley or Halifax Hard Bed) Ganister, which provides the staple raw material on which the local silica-brick making

industry has been built up. So important are the products of this minor industry to the major metallurgical industries, that the mining of ganister measures associated with the Halifax Hard Bed Coal may fairly claim to rank as a national key industry essential to the existence and certainly to the prosperity of all the Sheffield trades, and it is clear that, without a supply of such ganister, modern methods of steel making as practised in Sheffield could not be continued. From various beds interstratified among the Halifax Group of Coal Measures, come also the main supplies of fireclay goods manufactured in Yorkshire, both of firebricks used for the construction of the cooler parts of furnaces and also of the high-quality material which is used for crucible making and for the lining of other vessels to contain the molten steel. For satisfactory service in steel making furnaces and vessels, no acid refractory material has yet been discovered which is either so reliable or so capable of maintaining its rigidity at the highest temperatures as brick made from best mined ganister from the seat-earth of coals of the Halifax Hard Bed Group. Partly by reason of the mischief wrought by former unsystematic outcrop mining of these coals and ganisters, and largely because of the ever-increasing labour charges, the average cost of ganister mining has increased so much in recent years that notwithstanding the proved existence of local reserves, sufficient at the present rate of working to last for centuries, in all circumstances where bricks made from other more cheaply worked silica rocks (with or without admixture of ganister) will perform the required service, it is no longer economically profitable to use the Sheffield ganister alone.

For cheaply available supplies of second-grade highly siliceous rocks required for the purpose of "dilution," the Sheffield area is not so well provided as are the coalfield districts of North and South Wales and Durham, but, with the Middle Rock of the Don Valley and the superficial deposits full of quartzite pebbles in the Bawtry district ready to their hand, local silica brick makers are not likely to go short.

Of highly siliceous special fireclays of the class required for reheating furnaces, gas-works, and bye-product coke-oven plants, the foundered Triassic rocks found in hollows of the High Peak Limestone Plateau provide an abundant if inconstant and not very accessible supply, which for many purposes can be supplemented or replaced by the ganister under-bed, by artificial mixtures of crushed ganister or other siliceous rock, or by silica sand from Jurassic or Cretaceous sources incorporated with the flux-free fireclays found in association with the Halifax Coal Measures Group. Other (generally less

refractory) qualities of fireclay are available in abundance from the seat-earths of the thick coals of the Middle Coal Measure Series.

Of actual and potential reserves of dolomite rock which will serve for the making of calcined and shrunk dolomite or "basic," the Sheffield district has an illimitable supply. Of native dolomite, in which the magnesium oxide is over one-fifth of the total weight, there is in the Middle and Upper beds of the Lower Magnesium Limestone a twenty-five mile long outcrop extending from near Mansfield to north of Doncaster, and it would seem that in this district, if anywhere in Britain, we have the requisite raw material and economic conditions for the successful extraction and concentration of salts of magnesia and the manufacture of English magnesite.

From the point of view of the geologist it may be of interest in conclusion to point out that some part of each of the geological system which comes to outcrop in the Sheffield district is already of some importance to the local makers of refractories, and has been drawn on to supply some quotum of refractory material for the iron and steel industries. Between the rock beds and geological horizons which are being exploited to supply existing demands there occur many other beds, the composition and therefore the refractory qualities of which are quite unknown.

With each successive major or minor adjustment of metallurgical furnace practice there comes a corresponding change in the service demanded from the refractory materials, and an opportunity for experiments to discover what new or standard materials will serve. In general, except in some few melting furnaces, the most important of the refractory qualities asked for in furnace linings is not merely that the material as a whole shall have a melting point which is high, but rather that its constituent particles or pieces shall maintain their size, shape and relative positions with any changing temperature to which they are subjected. Each manufacturing process imposes its conditions, and for each some specific material has by long experience of trial and error been selected. Trials continue and there is no sign that in the infant science of the study of refractories any finality has been or will be reached. Is it not likely that among the vast Carboniferous Formation and in all the later geological series, which in this district collectively form a geological column of sediments fully 20,000 feet thick, a systematic chemical survey of the component measures will discover other deposits of materials whose refractory properties are at present unknown, but which may prove of special value for some particular purpose? It will be the business of the newly-

founded Department of Refractories at the University of Sheffield to collect and investigate this information respecting all the measures present in the Sheffield district.

(For Discussion see end of succeeding paper.)

XXVIII.—Notes on the Evolution of the Ganister Industry in the Sheffield District.

By J. Holland.

THESE few notes are very incomplete, and any additions or corrections will be appreciated. I have purposely left out any reference as to what is, or is not *ganister*, or to its chemical and physical properties, or geological position in the scheme of Nature, as these are dealt with elsewhere.

The earliest known use of ganister stone was for "metalling" roads, particularly in the Stannington and Loxley districts, where the stone was got very cheaply from the outcrops, and considerable quantities were obtained in the "riddings" from fields.

In my young days it was not uncommon to see walls in these districts built of large quantities of good ganister stone taken from the fields. The stone was excellent for road metal, and the cost was low. The Highway Authorities in 1865 paid three shillings per cube yard, say, one shilling and sixpence per ton. By 1871 it had increased to four shillings and sixpence per cube yard, and even as late as 1900 it could be bought at about eleven shillings per ton carted into Sheffield.

It is, however, its use for metallurgical purposes which most interests us, and of these purposes, it was first used for lining the holes of the *crucible furnaces*. The material was then got by scraping the roads which had been "metalled" with ganister stone, and it is generally believed that the first to so apply it was Huntsman, who came from Doncaster to Handsworth, near Sheffield, in 1742, where he experimented and perfected his invention of making crucible cast steel. This process is carried on extensively to-day on practically his original lines. He eventually established his works in Attercliffe in 1772, and the first metallurgical use of ganister would thus be between the two dates mentioned.

By the year 1774 there were three firms making cast steel: Huntsman, Bolsover, and Marshall.

By 1787 there were five steel refiners and fifteen steel converters in Sheffield.

As comparatively so small a quantity of road-scrapings was required to meet the needs of these furnaces, no undue call was made upon the material; but the time arrived when the roads could not yield sufficient for the gradually expanding trade (by 1846 there were ninety-eight furnaces making cast steel), and it then became a question of manufacturing a material similar to these road-scrapings.

There can be very little doubt that the first man to foresee the future possibilities of the industry and to put down a grinding pan to manufacture ground ganister was Joseph Bramall, Senr., of Oughtibridge, early in the fifties, and, in order to approximate as nearly as possible to the road scrapings hitherto used, he put into his grinding mill, in addition to ganister rock, a small proportion of fireclay and horse-droppings, which would probably give as good a working result as any present-day practice. This mixture he sold under the name of "pulverized sand."

In 1855 William Hollis entered the field as a ganister grinder, at Victoria Road, Sheffield Park.

The great advance in the trade came the following year, when Bessemer brought his process before the public, and the introduction of his steel converter quickly called for much more extensive supplies of ground ganister, as, by the end of 1861, about seventy tons of Bessemer steel per week were made in Sheffield, and at this date the ganister grinders were Bramall, Hollis, Russell and Young.

By 1868 there were added Butterell, Longden, Nicholson, Oakes and Lowood. In 1871 there were twelve grinders, and others have since been added.

From the small beginnings mentioned the rapid advance of the industry is shown by the fact that by 1908 there were over 80,000 tons of ganister produced in the West Riding of Yorkshire alone, in addition to large quantities in other districts.

Although the first mill-ground ganister was termed by the manufacturer "pulverized sand," and a little later "ground gannister" (spelt in those days with two "n"s), it was more generally called by the old melters (most probably from its humble origin) "muck." It was a common experience of the writer on his first introduction to the "trade" to see the old melters bring their orders (in those days invariably verbal orders) for "five or six loads o' muck." Naturally the manufacturers' ambition was to rise above the level of "muck grinders," and by constant reiteration of the word ganister it gradually evolved into "ganister muck," and finally into "ground ganister," but this last concession only came with the arrival of the then younger school of melters.

The most important metallurgical use to which ganister is put is in the manufacture of silica bricks, which were called for on the introduction of open hearth steel furnaces, the invention of Siemens, who was the first to apply regenerative chambers for steel making in 1856. He had been experimenting in Birmingham several years before he built his first practical furnace at Landore in South Wales. In his experiments he had experienced great difficulties in producing a suitable lining for his furnace—neither the ramming with ground ganister, as in the crucible holes or Bessemer converter, nor the building of the furnace with blocks of silica stone was successful—for reasons which are now well known. He, therefore, in conjunction with Allen, commenced to make bricks of the Dinas rock so abundant in the Vale of Neath. This they achieved by grinding the rock and mixing with it a small portion of clay and lime, and afterwards drying and burning in a similar manner to the present-day custom. These bricks were made at the old Neath Works, and were thus the first silica bricks ever manufactured.

This note may appear rather outside the field covered by the title of this paper, but it is essential to trace the development of the trade in our district, because one of the first Siemens' furnaces erected after that at Landore was in Sheffield —I think at Vickers' Works—and others quickly followed. For these early furnaces in Sheffield I understand Siemens sent some of his own trained men from South Wales to work them, and also sent supplies of Dinas bricks from Neath.

It quickly became obvious that, with the local resources of ganister, silica bricks could be made quite well in the Sheffield district, and Young (a nephew of Allen) who, for some years, had been grinding ganister at Oughtibridge, put up a small kiln and made the first silica bricks in England on the site of the present Oughtibridge Works. This would be about 1858 or 1859. There is a stone still in existence in a kiln at the Oughtibridge Works, dated 1860. These works were shortly afterwards purchased by Edward Brooke, then a fire-brick maker in the Huddersfield district. At the time of this purchase there were two small kilns only, and the most prominent feature in the works was an excellent "skittle-alley," where the workmen devoted a good portion of their time.

For some years these were the only works manufacturing silica bricks in this district—until 1870, when Lowood built his works at Deepcar and commenced to make silica bricks.

Several other manufacturers have erected silica brickworks since that time, and the industry is a very important and rapidly expanding one.

JOINT DISCUSSION ON THIS AND THE PRECEDING PAPER.

Mr. F. H. Brooke:—What Mr. Holland has told you about the establishment of the ganister industry is quite correct. There is no doubt that in Sheffield we have a very excellent material, and I hope in the future, as in the past, it will play a great part in the development of the steel trade and like industries. The minerals do vary, like Prof. Fearnsides states. There are irregularities in the thickness of the ganister. Where the ganister is thin the coal is thick, and we get a large amount of compensation in that respect. Also as regards the quality of the coal we find that has a good effect in helping to burn the brick. It contains a certain amount of sulphur, which helps to knit the brick together, and most of the local brick firers prefer the ganister coal than the best coal from South Yorkshire.

Mr. Cosmo Johns:—I think it is a most excellent thing that this Refractories Section should, when visiting various centres, call upon some competent investigator to describe the geology of the particular district from a technological standpoint and thus bring together related data, both published and unpublished, and rendering it accessible. Here we are extremely fortunate in that the task falls on Prof. Fearnsides, who has, since his appointment to the Sorby Chair of Geology in this University, taken a keen interest in many technological problems affecting this district, and has been able to render very valuable services to the metallurgical and related industries. From the very full description given by Prof. Fearnsides of our resources in, and characteristics of, the raw materials suitable for manufacture into refractory materials, one can easily see why Sheffield has developed into such an important and specific type of metallurgical centre. In no other district can we find a unique siliceous rock like the Hard Bed Ganister, famous fireclays, coking and steam coals, with abundant dolomitic limestone, of the quality required for the basic hearths of open hearth steel melting furnaces, all cropping out within a few miles of each other. I was glad to hear from such a competent authority as Prof. Fearnsides that there were such abundant, if not inexhaustible, supplies of easily-worked dolomitic limestone with the physical and chemical qualities required by the metallurgical industry in the neighbourhood. It is to be hoped that this information will serve to calm the perturbed minds of those people who were afraid that the only suitable dolomite was located in the immediate neighbourhood of a particular lime works. Yet despite the amount of most valuable data that Prof. Fearnsides was able to communicate

one could not help being struck by the fact that what is known of the resources of the district is as nothing compared with what is unknown. The greater part of the deposits in the Carboniferous Series of rocks still await investigation. Opportunities that occurred in the past were allowed to pass, and a vast amount of work still remains to be done before it can be said that even a preliminary survey of our local resources has been completed. I should like to say how much I appreciated the note by Mr. Holland. This again is a feature that the Refractories Section might with advantage repeat in other districts. The origin of any special or local trade is always of interest, and when dealt with by an authority, like Mr. Holland, of historic value. We need never be ashamed to put on record the beginnings of our industries.

Prof. W. W. WATTS:—It is particularly interesting to me to hear Mr. Holland's paper and hear how ganister came to be used here. It is an interesting example that we have not waited for the Great War before utilizing waste materials.

What I more particularly wanted to call attention to is the remarkable characters of the Carboniferous System. It seems that everything that took place during the formation of these rocks has produced material suitable for human progress. Not only have we all varieties of coals and ironstones and other useful substances, but also refractory materials. We have many sandstones, but few with suitable qualities outside the Carboniferous System.

Mr. ALLEYNE REYNOLDS:—At the time I was with Vickers I had occasion to search through the original drawings of what I believe were the first open hearth melting furnaces in this district; their date was 1870, and they were a pair of 4½ ton furnaces.

Mr. W. J. REES:—Prof. Fearnsides' paper provides a comprehensive and exceedingly useful summary of the supplies of raw refractory materials on which the industry can draw, and the resources indicated are such that there is little fear of the industries which have made Sheffield famous running short of the primary raw materials necessary for the construction and maintenance of high temperature furnaces.

To those working in the newly established Department of Refractory Materials at Sheffield University one of the most interesting parts of the paper is that dealing with the clays occurring throughout the Carboniferous System, and it must certainly be one of our first tasks to make as systematic an investigation of these clays as is possible. Many beds are

already known to occur, of the composition and refractory properties of which there is no knowledge. The co-operation of all coming in touch with clays in this district will be of very great advantage and assistance to the laboratory. The support already received is such as to be a very great encouragement to us.

The immense reserves of dolomite suitable for use in basic refractory linings, to which Prof. Fearnsides directs attention, will be an asset of great value to the Sheffield district now that the steel industry is making such rapid strides in the development of the basic process and the utilisation of our home supplies of phosphoric iron ores.

An inquiry into the resources of refractory sands, in or easily accessible to the Sheffield district, for moulding and for lining hearths and furnace bottoms is a matter of some urgency in view of the pre-war dependence on sea-borne supplies. In the case of moulding sands a good deal of preliminary research work into the essential properties of such sands is necessary before the value of a sand for this purpose can be definitely determined.

Prof. P. G. H. BOSWELL:—Prof. Fearnsides touched on, and Mr. Cosmo John also raised, the question of utilizing British resources of sands in the steel industry, and the only point I wish to raise is the question of foreign supplies.

The Ministry of Munitions has persistently endeavoured to put the users in touch with the scientists who are investigating the qualities of the various materials submitted to them. There has been expressed in this town a doubt as to whether we can replace those foreign supplies of sands, and if, after the war, the price of British sands will be so low as that of the foreign. There is no doubt, I think, that steel manufacturers have modified their practice to some small extent in order to adopt the British materials, in some cases even before the foreign supplies were cut off. There ought to be no necessity to go back to foreign sources at all. Not only do I think that we can be independent of foreign supplies entirely, but I am coming to the conclusion that every district will soon be very largely self-supporting.

A rather interesting fact is that where foreigners have come into this country and are helping in our foundries they obtain quite good results with British, and not foreign, material. Of course the important economic question is, that where British materials are situated near to the works, the price will be lower than for foreign sands even when they are brought in as ships' ballast. The questions of inland water-transport

and railway freights need serious consideration, if home supplies are to be used.

The matter should be looked upon with a broad mind and practice adapted to the materials available. Where open-mindedness has been shown in the works, and people actually in charge have pursued this policy, they have been able to use British supplies with great success. It is only where the prejudice of the workmen has been allowed to control matters that the mistake has been made of thinking we must depend on Belgian or French material.

Prof. FEARNSIDES, in reply, returned thanks to those who had spoken in the discussion, and also to all those present at the meeting for their very kind reception of his paper. He quite agreed with what Prof. Boswell had said about the outlook for the future, and could foresee that when the practice of making the best of local supplies of sands and of refractory materials generally shall have been placed upon a really scientific basis the Sheffield district at any rate will become more nearly self-supporting in these materials than ever it has been in the past.

XXIX.—The Standardization of Tests for Refractory Materials (Part I.)

Report of the Committee, consisting of Prof. J. W. Cobb, B.Sc., Dr. H. G. Colman, Major C. W. Thomas, Messrs. F. H. Brooke, W. J. Brooke, A. Cliff, J. Allen Howe, Cosmo Johns, W. J. Jones, B. Moore, D. J. Pinkerton, W. J. Rees, and Dr. J. W. MELLOR, Hon. Sec.

PROVISIONAL SPECIFICATION.

Standard Methods of Testing Refractory Materials.

THE purpose of the present report is to draw up a standard scheme for conducting tests on refractory materials. This should be a prelude to a specification of tests which particular types of refractory material should withstand when used in a particular furnace or in a particular part of a furnace. The Refractory Materials Committee of the Institution of Gas Engineers has laid the foundation for specification work, and it became obvious to that Committee, as the building progressed, that attention should also be directed to *the mode of testing the materials* in order that comparable results should be obtained by maker and user. I have fortunately received from that Committee permission to use such of their data as are considered necessary for the present report. In spite of the greatest care, it is anticipated that this provisional report will have all the blemishes which pertain to first attempts at standardization, but it is hoped that as our experience grows the defects will be eliminated, and weaknesses strengthened by earnest criticism.

The purpose of standardizing the mode of conducting the tests is to eliminate, as far as possible, variations in results due to peculiarities in the methods of conducting the tests. It is well known, for example, that the softening point of a fireclay or firebrick is not a clearly defined constant like the melting point of a crystalline solid, and similar remarks apply to many of the other constants of firebricks and fireclays. If comparable results are to be obtained comparable methods of testing must be adopted. Even if a set of standardized tests be adopted, they must be revised periodically to allow for improvements.

Two types of tests are available, namely, those which allow the results to be expressed precisely as a definite number, and those in which the results can be expressed only in less definite or in vague terms. For example, the differences in the action of different types of flue dust cannot be expressed by number, and a series of comparative terms have to be employed, which have more or less a personal significance. Many useful "homely" tests are not suited for comparative measurement, and consequently are not suited for standardized tests. Such tests have to be excluded from a report on standard methods of testing as a preliminary to specification work. The tests are not necessarily intended for checking the materials in a fireclay works since that is the private business of the firm itself. For example, a mere determination of the loss on ignition of a dried clay may suffice to show whether the clay and grog have been mixed in the right proportions; and the treatment of silica material with hydrofluoric and sulphuric acids may also suffice for checking the mixing. In any case, the final product should satisfy the specification when tested according to standard processes.

I.—The Analysis of Fireclays, Raw Ganisters, Quartzose Rocks, and Manufactured Products.

It is scarcely possible to over-emphasize the importance of getting a fair average or representative sample of all materials for analyses or testing.

Determination of hygroscopic moisture.—About 5 grms. of the finely-ground clay are dried in a toluene oven or air-bath maintained at 110° until there is no further loss in weight —three to four hours is usually sufficient.

Determination of the loss on ignition.—About 1 grm. of the dry clay is heated in a platinum crucible, first over a small flame, then over a Méker or Teclu burner, and finally over a blowpipe flame for about 20 mins. The crucible is allowed to cool in a desiccator and weighed. The crucible and contents are again heated over the blowpipe flame for 5 mins., cooled, and weighed. Low results are usually due to the incomplete combustion of the carbon; high result may be due to losses by spurting produced by heating too rapidly.[1]

Determination of the silica.—The ignited clay in the platinum crucible is intimately mixed with 10—15 grms. of sodium carbonate. The mixture is gently heated over a Méker or Teclu burner, and finally fused at a bright red heat for

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[1] When many determinations have to be made, the ignition of precipitates is conveniently done in a muffle at a suitably high temperature.

30 mins. for firebricks, and 15—20 mins. for fireclays or silica materials, or until the contents of the crucible are in a state of quiet fusion. The red-hot crucible is dipped in water to about two-thirds of its depth in order to solidify the contents rapidly. The cake is extracted with as small an amount of water as possible, and the washings collected in a 250 c.c. basin —the cake will probably be detached from the crucible by this treatment, and is transferred to the basin. The basin is almost covered with a clock-glass, and 30 to 35 c.c. of concentrated hydrochloric acid are run into the basin; the covered basin is kept warm on a water-bath until all action has subsided and the cake has disintegrated, and any large pieces which remain are crushed into powder with a small agate pestle. The platinum crucible and lid are washed with hydrochloric acid and hot water, and the washings poured into the basin. The solution is evaporated to dryness, and the contents heated in an air-oven at 110° until dry. The mass is moistened with concentrated hydrochloric acid, 60—70 c.c. of hot water added and the liquid filtered; the precipitate is washed with hot water until free from chlorides. The filtrate is returned to the basin, evaporated to dryness, and the mass is heated as before until it is free from hydrochloric acid. The residue is again digested with hydrochloric acid and about 60—70 c.c. of hot water, filtered, and the residue washed with hot water until free from chlorides.

The two filter-papers are transferred to a weighed platinum crucible, and charred slowly without flame. The carbon is burnt off slowly, and the crucible and its contents heated over the blowpipe for 15 mins. with the lid off, and then 5 mins. with the lid in position. The result is entered as "uncorrected weight of crucible plus silica." The silica contains small quantities of the oxides of titanium, phosphorus, aluminium, and iron. 5 c.c. of water are added to the crucible together with a few drops of concentrated sulphuric acid in order to prevent the subsequent volatilization of titanic fluoride. About 15 c.c. of hydrofluoric acid are carefully added a few drops at a time. The solution is cautiously evaporated to dryness on a sand-bath. The outside of the crucible is freed from sand, the crucible ignited over a burner for 5 mins., and weighed when cool. The result is entered as "weight of crucible + residue." Later the alumina is ignited, together with the silica residue, in the same crucible.

The ammonia precipitate.—From 2 to 3 grms. of solid ammonium chloride and an excess of ammonia are added to the hot filtrate (80°—90°) from the silica, and the solution filtered immediately. The precipitate is washed immediately

two or three times with hot water, a hole made in the filter paper, and the precipitate washed back into the beaker from which it has just been filtered. The precipitate is redissolved in a slight excess of hydrochloric acid, and the filter paper is washed until free from chlorides with hot water and kept for ignition later. The combined filtrates are heated to 80°—90°, an excess of ammonia solution is added, the liquid filtered into the beaker previously used, and the precipitate washed free from chlorides by means of a slightly alkaline solution of ammonium nitrate (made by mixing 5 c.c. of concentrated nitric acid with water, adding ammonia until alkaline, and making the solution up to a litre), care being taken that the alumina precipitate does not at any time become dry. The combined filtrates are evaporated to about 100 c.c., and, whilst still hot, 2 to 3 c.c. of ammonia are added. The liquid is filtered, and the precipitate washed free from chlorides with hot ammonium nitrate solution. The filtrate is reserved for the determination of lime and magnesia.

The three filter papers containing the "alumina" precipitate are dried in the platinum crucible containing the silica residue; the crucible is heated very slowly until the paper is charred, and the temperature raised until all the carbon is burnt off, finally heating for 15 mins. over a Méker burner. After weighing, the ammonia precipitate is very slowly dissolved by fusing with 5 to 6 grms. of fused potassium bi- or pyro-sulphate. The cold cake is transferred to a basin with about 150 c.c. of water, and 10 c.c. of concentrated sulphuric acid are added. The mixture is heated on a water-bath until dissolved and made up to 250 c.c. This solution is retained for determination of the iron and titanium.

NOTES.—(*a*) If the clay contains manganese, 2 or 3 c.c. of bromine water are added to the solution before the ammonia precipitation, and the liquid filtered at usual. In the second precipitation 1 or 2 c.c. of bromine water are again added, and the same procedure followed as above described.

(*b*) In the case of a silica brick (containing over 92 per cent. of silica), where the ammonia precipitate is below 5 per cent., only a slight excess of ammonia is added to the washings from the silica, and the excess boiled off. The liquid is filtered and the precipitate washed with ammonium nitrate solution as rapidly as possible. One precipitation only is necessary.

Determination of ferric oxide.—A colorimetric process is used for materials which ignite to a white and buff colour; the ordinary permanganate process for those which give deeper colours. The colour of the sample in the crucible after it has been heated for "loss on ignition" is a good criterion to determine which process is the better. A suitable amount of the solution obtained by fusing the ammonia precipitate with pyrosulphate is made up to 250 c.c. 25 c.c. are sufficient for

a normal clay containing not more than 1 per cent. of ferric oxide. 5 c.c. of standard iron solution (see below) are made up to 100 c.c. with distilled water. The latter solution is transferred to a burette reading to 0·05 c.c., and another burette is filled with distilled water. Two similar glasses are now required—the test glasses of a colorimeter can be used. Specimen glasses with parallel sides—about 3 cm. square and 8 cm. high—serve excellently. A mixture of 10 c.c. of the solution to be tested with 10 c.c. of potassium thiocyanate solution is made in one test glass, and in the other a mixture of 10 c.c. of a solution of potash alum with 10 c.c. of thiocyanate solution. The tints are viewed by light transmitted through the parallel sides of the glasses. The standard iron solution is added to the test glass with the potash alum solution and an equivalent amount of distilled water to the other, stirring thoroughly after each addition. When the tints of the liquids in the two test glasses are the same the amount of iron oxide in the sample can be computed.

EXAMPLE:—Using 1 grm. of clay and the above mentioned dilutions the percentage of Fe_2O_3 is given by $\frac{V}{8}$ where V represents the number of c.c. of iron solution used; if w grams of clay be taken and v c.c. of the pyro-fusion solution be diluted to 250 c.c. the percentage of Fe_2O_3 is $\frac{25V.}{8v.w.}$

For materials containing larger amounts of iron, the pyrosulphate fusion is made up to about 150 c.c., and 20 c.c. of concentrated sulphuric acid employed. If the titanic oxide is to be ignored, the solution can be reduced with purified zinc (about 10 grm.) until a drop gives no reddish-brown coloration with potassium thiocyanate. The reduced solution is then diluted to 250 c.c., and titrated with standard potassium permanganate in the usual manner.

If the titanic oxide is to be determined, the solution is to be reduced with sulphur dioxide or ammonium or sodium bisulphite. The solution under treatment should be acidified with sulphuric acid (1 : 1). Add a concentrated solution of of ammonium bisulphite, and agitate the mixture thoroughly; or pass a current of sulphur dioxide from a "SO_2 bomb" through the acid solution. Gradually raise the temperature of the solution to boiling, and, when a drop no longer gives a brownish-red coloration with potassium thiocyanate, the ferric oxide is all reduced. To remove the excess of sulphurous acid place the flask on a sheet of asbestos on a tripod. Add 15 c.c. of dilute sulphuric acid (1 : 1). Cover the flask with the perforated lid of a Rose's crucible. Pass a current of carbon dioxide at the rate of 3 to 4 bubbles per second through the solution. The carbon dioxide should be washed by passing

it through a column of pumice soaked in copper sulphate and a water wash-bottle. The delivery tube passes through the hole in the cover of the flask. Meanwhile the flask is heated to the boiling point of the solution. The velocity of the carbon dioxide is then reduced to about 1 bubble per second. After 20 to 30 minutes' boiling the escaping steam will probably be free from sulphur dioxide, as shown by its failure to discolour a mercurous nitrate test-paper. In that case, place the flask in a dish of cold water to cool, while the current of carbon dioxide still bubbles through the solution—1 bubble per second.

When cold, the contents of the flask can be titrated with a standard solution of potassium permanganate, as indicated below. The titanium oxide is not reduced by the treatment with ammonium bisulphite.

Standard iron solution.—0·6302 grm. of ferric potassium alum are dissolved in water, 5 c.c. of concentrated sulphuric acid added, and the solution made up to 1 litre (1 c.c. = 0·0001 grm. of Fe_2O_3.

Potassium thiocyanate solution.—97 grms. of potassium thiocyanate per litre.

Potash alum solution.—0·05 grm. of alumina (free from iron) are fused with 5 grms. of potassium pyrosulphate, the cold cake extracted with water, 10 c.c. of concentrated sulphuric acid added, and the solution made up to 1 litre.

Determination of titanium.—For the colorimetric determination of titanium similar test glasses to those employed for the iron determination are used. 50 c.c. of the solution of the cake from the pyrosulphate fusion are mixed with 7 to 8 c.c. of hydrogen peroxide (free from fluorides), and the solution made up to 100 c.c. 5 c.c. of "standard titanium solution" are mixed with 5 c.c. of hydrogen peroxide, and the solution made up to 100 c.c. One of the test glasses is about half-filled with the solution to be tested. 10 c.c. of the diluted standard titanium solution is pipetted into the glass, and water added from a burette to the latter solution until the tints of the liquids in both glasses are similar. The tints are viewed by light transmitted through the parallel sides of the test glasses.

EXAMPLE :—If one gram of clay be taken, and the dilutions given above employed the percentage of TiO_2 is $25/(10+v)$ where v is the volume of water added to the 10 c.c. of diluted standard titanium solution.

When w grms. of clay are taken and V c.c. pyro-fusion solution are diluted to 100 c.c. the percentage is $\frac{1250}{(10+v)\,V.w.}$

The weights of ferric oxide and titanic oxide in the ammonia precipitate have now been determined, and if these are subtracted from the total weight of this precipitate the difference will represent the weight of the alumina in the given sample.

Standard titanium solution.—1 grm. of pure titanic oxide is fused with 10 grms. potassium pyrosulphate, the cold cake extracted with cold water, and the 10 c.c. of concentrated sulphuric acid added. After dissolving at as low a temperature as possible the solution is made up to 1 litre. 1 c.c. = 0·001 grm. of TiO_2.

Determination of lime.—The filtrate from the ammonia precipitate is boiled with 1—3 grms. of ammonium oxalate, and 5—10 c.c. of concentrated ammonia solution are added. The solution is agitated and allowed to stand on the water-bath for two hours. The liquid is filtered, the precipitate washed once (the filtrate is reserved for the determination of magnesia), a hole made in the filter paper, and the precipitate washed into the beaker from which it has been filtered; the precipitate is redissolved in nitric acid, ammonium oxalate and ammonia are added to the boiling solution as before. The liquid is allowed to stand 2 to 3 hours, filtered, and the precipitate washed free from chlorides with hot water. The dry precipitate is ignited in a weighed platinum crucible. The ignition is conducted slowly at first, and finally over a blast until the weight is constant—about 15 minutes is ample. The lid should be placed on the crucible for the last five minutes. The crucible is weighed rapidly when cool.

Determination of magnesia.—1 to 2 grms. of sodium ammonium phosphate are added to the first filtrate from the ammonium oxalate precipitate, and the mixture boiled whilst covered with a clock-glass. 10 c.c. of concentrated ammonia are added, and the mixture allowed to stand for at least 3 hours. The mixture is stirred vigorously when cold, filtered, and the precipitate washed once with cold water, rejecting the filtrate. A hole is made in the filter-paper, the precipitate washed into the beaker from which it has been filtered, and the ammonium magnesium phosphate redissolved in nitric acid. The solution is heated to boiling. 1—2 grms. of sodium ammonium phosphate and 10—15 c.c. of concentrated ammonia are added, and the mixture allowed to stand 1 or 2 hours. The cold mixture is thoroughly stirred, filtered through a weighed Gooch crucible, and the precipitate washed free from soluble phosphates with cold ammonia solution (1 : 8). The dry precipitate is ignited, cooled, and weighed as magnesium pyrophosphate.

Determination of alkalies.—About 0·5 grm. of finely powdered dry clay is intimately mixed with about 0·5 grm. of ammonium chloride and 3 grms. of calcium carbonate in an agate mortar, and transferred to a platinum crucible, rinsing out the mortar with another gram of calcium carbonate. The crucible and contents are heated over a small Bunsen flame for about 15 minutes. The lid is kept partly on the crucible whilst

the ammonium chloride is being volatilized, then placed in position, and the crucible and contents heated for 1 hour, with the lower third of the crucible at a dull red heat, but not sufficiently high to melt the mass. The crucible is allowed to cool slowly, the cake is transferred to a porcelain dish, and the crucible is thoroughly washed with hot distilled water. After standing 2 or 3 minutes, the cake in the dish is gently crushed to powder with an agate pestle. The mass is digested with 80 c.c. of water for 30 minutes, filtered, and the precipitate washed with hot water eight or nine times; the filtrate should occupy 100—150 c.c. The precipitate is rejected. 10 c.c. of ammonium carbonate (see later) are added to precipitate the lime from the boiling hot filtrate; the liquid is filtered and the filtrate retained. A hole is made in the filter paper and the precipitate washed into the same beaker from which it was filtered, and dissolved in hydrochloric acid (about 5 c.c.). The solution is boiled and a slight excess of ammonia and ammonium carbonate added, and the mixture is filtered into the same beaker as before. The solution is evaporated to dryness in a platinum basin, and the dry residue ignited by gradually raising the temperature to faint redness in order to volatilize the ammonium salts. When cold, 3 c.c. of ammonium carbonate are added to the residue in order to precipitate the last traces of lime, the liquid covered with a clock-glass, and allowed to stand overnight. The mixture is filtered into a small platinum dish; the precipitate is washed with a solution of ammonium carbonate, and the filtrate is again evaporated to dryness on a water-bath. As the liquid tends to spurt during the early stages of the evaporation, the basin is covered with a clock-glass, and any liquid adhering to the glass is washed back into the basin. When dry the contents of the dish are moistened with a small amount of concentrated hydrochloric acid and again evaporated. The residue is ignited at a dull red heat, cooled, and weighed; this residue is then washed out into a small porcelain dish and the platinum dish reheated and weighed. The difference in weight represents the alkali chlorides.[1] The solution containing the alkali chlorides is poured into a small porcelain dish, and evaporated almost to dryness with perchloric acid, 10 c.c. of water added, and again evaporated almost to dryness. Six times the weight of the mixed chlorides represents the number of c.c. of 30 per cent. perchloric acid of specific gravity 1·20 to be used in the test. The residue is treated with a mixture of 97 volumes of absolute alcohol, 3 volumes of water, and 0·25

[1] It is advisable to make a "blank" determination of the alkalies in the ammonium chloride and calcium carbonate and to deduct this amount, if appreciable, from the weight of chlorides.

volumes of perchloric acid. The mixture is filtered at once through a weighed Gooch crucible, previously heated to 120°, and the residue washed with the alcohol mixture indicated above. The crucible and contents are then dried at 120° for about 45 minutes and weighed. The weight of the precipitate represents potassium perchlorate; this is calculated to potassium chloride, and subtracted from the weight of the mixed chlorides to give the weight of sodium chloride. The corresponding amounts of potash and soda are then computed.

NOTES:—(*a*) The first precipitate should be well washed, particularly if the amount of alkali is large.

(*b*) The first ignition must not be above 700°, and subsequent ignitions should not exceed a faint red heat, or alkalies will be lost by volatilization.

(*c*) The last washing should be made with ammonium carbonate solution, or the result will be too high.

(*d*) Porcelain or platinum vessels should be used for the evaporations. Glass vessels are objectionable.

Ammonium carbonate solution.—100 grms. of ammonium carbonate are dissolved in 100 c.c. of concentrated ammonia (0·880), and the solution made up to 500 c.c. with water.

For sulphur see next analyses. The sulphur determination in firebricks is only useful in special cases since a large proportion is often obtained by absorption from flue gases. As a result the interior of the brick might show $\frac{1}{4}$ per cent. and the marginal layers between 1 per cent. and 2 per cent.

II.—Analysis of Dolomite and Magnesite.

With the analysis of dolomite and magnesite bricks some slight modification of a clay analysis is necessary to prevent contamination of the various precipitates with calcium and magnesium compounds.

Hygroscopic moisture. (See clays.)

Loss on ignition.—This is conducted as described for clays and firebricks, but the ignition over a blast burner should be prolonged for another 10 minutes in order to ensure complete decomposition of the carbonates. The hygroscopic properties of calcium and magnesium oxides should be borne in mind when cooling and weighing the ignited sample. It must be observed that procelain crucibles of inferior quality having soft glazes are easily attacked by these materials.

Alkalies. (See clays.)

Determination of silica.—1 grm. of the finely ground material is mixed with about 10 grms. of dry sodium carbonate in a platinum crucible, and gradually heated until the mixture fuses; the contents of the crucible are maintained in a fused condition (with continual agitation) for about half-an-hour, or,

in the case of magnesite bricks, for 45 minutes, as the latter are very difficult to decompose.

For the dissolution, evaporation and filtration of the precipitate see clays.

It is necessary to use an excess of acid in washing the precipitate, owing to the fact that magnesium chloride in solution is hydrolysed on evaporating or boiling, and magnesium oxide or a sparingly soluble basic chloride remains with the silica.

Since not more than 5 or 6 per cent. of silica is present in an average magnesite or dolomite, two evaporations are unnecessary to remove the whole of the silica.

The precipitate of silica is ignited and weighed, and treated with hydrofluoric acid as described for clays.

Determination of alumina.—The filtrate from the silica is diluted to about 300 c.c., about 10 grms. of ammonium chloride and 2 to 3 c.c. of bromine are added, the solution heated to 80°—90° C., then a slight excess of ammonia is added and the solution heated for 5 minutes.

(The bromine is added to precipitate the manganese.) Prolonged boiling, large excess of ammonia and a too concentrated solution must be avoided, otherwise the alumina precipitate will be contaminated with much magnesia and lime. The precipitate is filtered and washed free from chlorides as described for clays.

As a general rule, an ordinary dolomite or magnesite rarely contains more than 4 to 5 per cent. of aluminium and iron oxides, and if the above conditions are maintained two or more precipitations of the alumina are unnecessary. If, however, it is suspected that some magnesia or lime has been precipitated, the precipitate is dissolved in hydrochloric acid, the solution diluted to 250 c.c., 7 or 8 grms. of ammonium chloride and slight excess of ammonia are added and the precipitate again filtered off and washed free from chlorides. The combined filtrates should now contain all the lime and magnesia.

The alumina precipitate is now ignited in the crucible with the silica residue, weighed and fused with potassium bisulphate as described under clays.

Lime.—To the filtrate from the alumina precipitate (which solution should occupy about 300 c.c.) is added about 2 grms. of ammonium oxalate and the solution heated until the salt is dissolved; great excess of ammonium oxalate, too much heating and strong solutions must be avoided, or magnesia will be precipitated here. Allow to stand for two hours, filter and redissolve as described for clays. Reprecipitate the lime with ammonium oxalate (2 grms.), taking the precautions noted

above. A second reprecipitation should always be made to ensure that all traces of magnesia have been removed from the lime precipitate.

The precipitate, after washing free from soluble salts, is ignited in a platinum crucible and weighed as usual.

Magnesia.—The combined filtrates from the lime precipitates are concentrated to about 300 c.c., 5 grms. of sodium ammonium phosphate are added, the solution is boiled for a few minutes and 10 to 15 c.c. of strong ammonia are added, then proceed with the precipitations as for clays.

The bulky precipitate naturally wants a very thorough washing with cold 10 per cent. ammonia solution, and the precipitate should be ignited throughout to a temperature of not less than 800° C. If too much ammonia or microcosmic salt be added, the precipitate will be contaminated with this salt, which is very difficult to remove by washing.

Iron and titanium oxides are determined as for clays.

Phosphorus and sulphur.—For the determination of these elements a separate 1 grm. of the sample is fused with sodium carbonate as for the silica. A sulphur-free flame is advisable for fusions and evaporations. An asbestos board with the crucible fitted in a hole protects the contents of the crucible when coal gas is used for the fusion. The silica is removed as usual and the filtrate made up to, say, 500 c.c. and 250 c.c., taken for each determination.

The portion for sulphur is neutralized with ammonia, and then just acidified with strong hydrochloric acid, the solution heated to about 90° C. and a hot solution of 2 to 3 grms. of barium chloride in 15 c.c. of water is slowly added, with constant stirring.

The solution, after standing 3 or 4 hours, is filtered through a small filter paper and the precipitate of barium sulphate washed free from chlorides with hot water.

The precipitate is then ignited to a dull red heat, moistened with a drop of sulphuric acid, again gently ignited, cooled and weighed. The sulphur is calculated as SO_3 by multiplying the weight of $BaSO_4$ by 0·343.

The phosphorus is determined in the other 250 c.c. by first neutralizing the solution with ammonia, adding 2 grms. of ammonium nitrate and 10 c.c. of strong nitric acid, heating to about 80° C., and a solution of 1 or 2 grms. of ammonium molybdate in 15 c.c. of water is added with constant stirring. The solution is allowed to stand 3 or 4 hours and filtered through a small filter paper.

The precipitate is redissolved in ammonia. Add 20 c.c. of ammonium nitrate solution and 1 c.c. of ammonium

molybdate to the ammoniacal solution of the ammonium phosphomolybdate first precipitated. Heat the solution at about 80° until gas bubbles begin to form, and add 20 c.c. of hot 5 per cent. nitric acid gradually with constant stirring. After standing 3 to 4 hours, filter through a Gooch's crucible, and wash with the mixture previously employed until no brown coloration is produced when a drop of the filtrate is brought in contact with a solution of potassium ferrocyanide. Dry the yellow precipitate and ignite it to about 800° C., and weigh as $24MoO_3.P_2O_5$. This weight, multiplied by 0·0394, gives the weight of P_2O_5 in half a gram of the sample.

III.—The Identification of the various forms of Silica in Silica Bricks.[1]

All the different modifications of silica (quartz, tridymite and cristobalite) possess physical characters by which each may be identified. Specific gravity, crystalline form and habit, and refractive indices, may, under certain conditions, be made use of for this purpose.

By a determination of the specific gravity quartz may be distinguished from the other forms of silica, and may be separated from them when in a finely divided state by the use of heavy solutions; but the specific gravities of tridymite and cristobalite, even when these minerals are in a pure state, lie so near together that no practical separation according to density is possible.

Owing to the small size of the grains and crystals in which the higher temperature forms of silica usually exist, it is obvious that the best means of identification come within the field of microscopical examination, and for this purpose either thin sections or powders may be used.

The crystalline form and habit are best studied by means of thin sections, and by their aid quartz is clearly distinguished from the two other forms of silica. Usually tridymite may be identified by the shape of its crystals and mode of twinning, more especially when it has been recrystallized under long continued heating. Often, however, both tridymite and cristobalite are present in silica bricks without any definite indication of crystalline form, and then some other means must be employed for their identification.

Between crossed nicols quartz is easily distinguished, by its greater power of birefringence, from tridymite and cristobalite; but here again there is no possibility of separating the last mentioned minerals from each other, for both are birefringent, and only feebly so, at ordinary temperatures.

[1] Contributed by Dr. H. H. Thomas, Petrographer to H.M. Geological Survey.

There remain, therefore, the all-important methods that depend upon the utilisation of those most characteristic physical constants of these three minerals, namely, the refractive indices.

The differences between the mean refractive indices of quartz (1·549), tridymite (1·477), and cristobalite (1·484) are sufficiently well marked to give us a definite means of identification, and the methods employed may be either that of Becke or that of Schröder van der Kolk.

These methods are familiarly known as immersion methods from the fact that the material to be examined, powdered to a degree of fineness sufficient to insure a separation of the component minerals, is placed in a liquid of known refractive index. The Becke or bright-line method, familiar to all petrologists, is that most often employed, and is no doubt generally applicable, for it furnishes a sensitive method of comparing the mean refractive index of any mineral with the refractive index of the liquid in which it is placed.

A still better method is that of Schröder van der Kolk, which is less well known. It is easy of application, yields results that are sensitive to a degree, and depends upon the fact that the dispersive powers of solids and liquids are seldom comparable. Even if a solid and a liquid have identical refractive indices for the light of the central portion of the spectrum, they will seldom have identical indices for red or for blue light. In such a case yellow light passing from the liquid into the mineral will suffer no refraction, but red and blue rays will be refracted and will give rise to red or blue fringes on one side or other of the dividing surface.

The method has been described by Schröder van der Kolk in his work, entitled *Kurze Anleitung zur Mikroskopischen Krystallbestimmung*, published at Wiesbaden in 1898. A discussion and practical exposition of the method was contributed by Mr. Allan Dick as an appendix to the Kaolin, China Clay and China-stone Handbook, Mem. Geol. Survey, 1914.

The method consists in viewing on a dark ground fragments of minerals placed in a liquid of approximately their own refractive index, and illuminated from below by oblique white light from all sides.

If a mineral and a liquid have the same refractive index for yellow light, then the mineral, if viewed under the conditions mentioned above, will have deep ultramarine coloured fringes. If the liquid is of higher refractive index the blue colour is paler and brighter, until with yet higher indices the fringes are composed of white light. If the liquid is of slightly lower refractive index than the mineral for yellow light, red and orange fringes result, and the colour becomes paler and brighter as the refractive index of the liquid is diminished.

If, therefore, we make a solution of mercury-potassium-iodide in water, dilute it until its refractive index for sodium light is 1·477, the mean refractive index of tridymite, and place in it powdered tridymite, the individual grains of this mineral, when viewed in the manner described, will show the characteristic ultramarine fringes. The same liquid, however, if used for cristobalite (R.I. 1·484), which has a slightly higher refractive index than tridymite, will give with this mineral orange colored fringes, while quartz has a refractive index so far removed from that of the liquid that it will be fringed with white light. It is thus possible to distinguish in one preparation the three minerals quartz, tridymite and cristobalite.

To take a simple case. A silica brick that has been in the flue of a furnace for a considerable period with one end raised to a temperature of about 1,600° C., and the other seldom raised above 400° C., will be clearly divisible into three parts. An outer part in which there appears to be no alteration and in which the original ganister fragments are obvious; a central black portion in which the ganister fragments gradually disappear towards the hotter end; and an inside white portion of granular texture in which all traces of the original ganister fragments are lost.

The central black portion consists almost entirely of re-crystallized tridymite and ferruginous material with some quartz in the less altered portion. This, powdered finely and placed in a liquid of refractive index 1·477, will show a deep ultramarine colour with dark ground illumination; the white inside portion of the brick similarly powdered and placed in the same liquid will give a somewhat bright orange colour under the same circumstances, showing that in this portion of the brick the silica is all in the form of cristobalite.

There is no method at present known that can equal this either in ease of manipulation or in accuracy of results, for it can be applied in the case of the finest powders, and requires no calculations; the only necessary precaution is occasionally to standardize the immersion liquid. This may be done either by means of a refractometer or by immersing in the liquid powdered tridymite. Should the fringes be too bright or light blue the liquid needs dilution to give the proper ultramarine colour, while if the fringes are inclined to red or orange some concentration must be effected.

Owing to the rapidity and ease with which solutions of mercury-potassium-iodide absorb and give up water and thus change their concentration and refractive index, they should be kept securely stoppered, and are best used in microscopic work under a cover-glass.

IV.—The Porosity, Water Absorption, and Specific Gravity Tests.

The porosity of a brick is to some extent a measure of the density and texture of the brick. With firebricks, a high porosity usually means that a brick will withstand abrupt changes of temperature very well, but will have a low crushing strength. The porosity test is conducted as follows:—A representative piece of the firebrick or refractory material to be tested is cut into rough cubes, about 2 in. size. The sample is dried at 110° for about two hours and weighed. It is then soaked for some hours, preferably overnight, in water under reduced pressure—a vacuum desiccator is very suitable for this purpose. The piece is then weighed while suspended in water as in ordinary specific gravity determination; the surface water is wiped off, and the piece is again weighed. The porosity, or the volume of the pores expressed as a percentage volume of the whole piece, is 100 times the quotient obtained by dividing the difference between weights of the piece soaked and dried, by the apparent loss in weight which the soaked piece suffers when weighed in air and then weighed suspended in water. Duplicates should agree within 0·2 per cent. With very dense or close-textured material, it is necessary to soak the sample for two or three days, otherwise the air bubbles in the centre of the piece are not displaced by water. The elimination of the air is also assisted by reducing the pressure inside the desiccator.

The specific gravity of the sample may also be calculated from the above data, since the apparent specific gravity of the lump is the quotient obtained by dividing the weight of the dry sample by the apparent loss in weight which the soaked piece suffers when weighed first in air and then suspended in water. The specific gravity of the solid material (powder) is the quotient obtained by dividing the weight of the dry test piece by the apparent loss of weight which the dry piece suffers when weighed in air and then suspended in water—after soaking'

Unless "water absorption" is specifically required, it is best to use an oil like turpentine, kerosene or paraffin in place of water, since the oil penetrates more rapidly into the pores. For the difficulty with sealed pores see TRANS., 7, 80, 1907.

The specific gravity of the oil which is used must be determined. The procedure is the same as with water, but the quotient obtained in the way described above must be multiplied by the specific gravity of the oil. For example, if the weight of the dry test-piece be 24 grms., and the apparent loss of weight when suspended in oil of specific gravity ·84 be 8 grms., then the true specific gravity of the material is $\frac{24}{8} \times \cdot 84 =$ or 2·52.

The apparent specific gravity of an average firebrick in lump usually varies from 1·5 to 1·9, and the powdered brick has a specific gravity ranging between 2·3 and 2·6; the porosity varies from 20 to 35 per cent.

V.—The Shrinkage of Clays on Drying and Firing.

The clay, dried at a temperature not exceeding 70°, should be crushed to pass a 28's sieve, made up with water to the proper working consistency[1] and thoroughly pugged or wedged. The clay is then moulded in a suitable mould made of metal or wood. The size recommended by the Committee on Standards of The American Ceramic Society (1918) is satisfactory. It is indicated in Fig. 1. The inside of the mould is thinly and evenly oiled with a rag soaked in paraffin oil. A piece of the clay

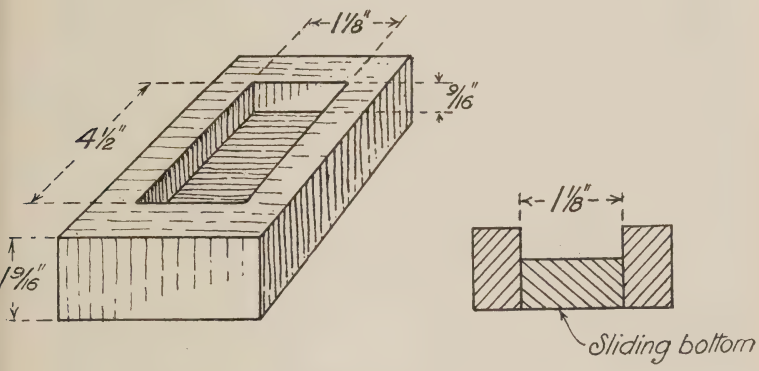

Fig. 1.

rather larger than is required to fill the mould is patted into a roll about 4 in. long and vigorously projected into the mould so that the clay spreads and fills the lower corners and edges. The fingers must be free from oil. The excess of clay is then cut off with a wire and the surface slicked with a palette knife or rubber slicker. The test piece so moulded is then marked —— with the vertical lines about 9 cm. apart, and allowed to dry first at the room temperature, then at 70°—80° (4—5 hours), and finally at about 110°. A portion of the clay from which the briquette was moulded is weighed on a watch glass, and after drying at 110° is again weighed. The weight of water

1 This subject will be treated in a later report. It might be added that it is difficult for one not accustomed to working clays to prepare the clay for this test. The same remark applies to the preparation of the clay for the determination of tensile strength (Section VI).

lost in drying is expressed as a percentage of the final weight of the dry piece.

The distance of the marks apart is again measured, and the linear drying shrinkage is expressed as a percentage of the length of the wet piece.

The test-pieces are then fired in a suitable muffle or thin-walled saggar. The effective firing space should be greater than 2 cubic feet. The fuel employed may be solid fire, gas, or oil. The rate of heating should not exceed five cones, or 100° per hour, until approximately 900° or cone 010a is reached, after which the rate of heating is decreased to about one cone per hour till the end of the operation.

For temperatures up to cone 6a (1,200°, a thermocouple pyrometer should be used in order to check fluctuations of temperature. The atmosphere in the kiln should be oxidizing.

For low grade clays, test-pieces can be drawn from the kiln at cones 010a (900°), 08a (940°), 05a (1,000°), 02a (1,060°), 1a (1,100°), 4a (1,160°), cone 6a (1,200°). For higher grade clays, test-pieces can be drawn from the kiln at cones 010a (900°), 05a (1,000°), 1a (1,100°), 4a (1,160°), 6a (1,200°), 8 (1,250°), and 10 (1,300°). If desired, the firing can be carried still higher, say, to cones 12 (1,350°), 14 (1,410°), and 16 (1,460°). When the test-pieces are removed from the kiln they are to be covered with hot sand, and kept at about 700° in an auxiliary furnace until all the test-pieces have been drawn. The pieces are then allowed to cool at the normal rate of the furnace.

The test-pieces when cold are examined, adhering particles of sand brushed off. The firing contractions of the different test-pieces are then measured and the results expressed as a percentage of the length of the wet piece, wet to fired and also dry to fired. The porosities are also determined. The results can be plotted on squared paper, with the temperatures or cones as abscissæ, and contractions or porosities as ordinates. The curve will show the approximate firing temperature required to obtain the maximum contraction of the clay; and the higher temperatures will show if the clay is likely to bloat.

The colour changes should be noted, and the relative hardness as compared by cutting or scratching with a steel knife. The specific gravity can also be determined at the same time as the porosity.

VI.—Tensile Strength of Dried Clays.

The tensile strength or tenacity of a clay or a body mixture is measured by the resistance which the dried clay offers to being pulled apart. The tensile strength of a clay has an

important influence on the losses which occur during the manufacturing processes. Cases also arise during the manufacture of special refractories, graphite crucibles, grog bricks, etc., where the strength of the bonding clay is very important. The tensile strength test is not an easy one to make satisfactorily.

It is exceedingly difficult to prepare the clay satisfactorily for this test. The prepared clay must be free from air blebs and laminations. It requires some practice to be able to make the briquettes with a homogeneous texture in all directions.

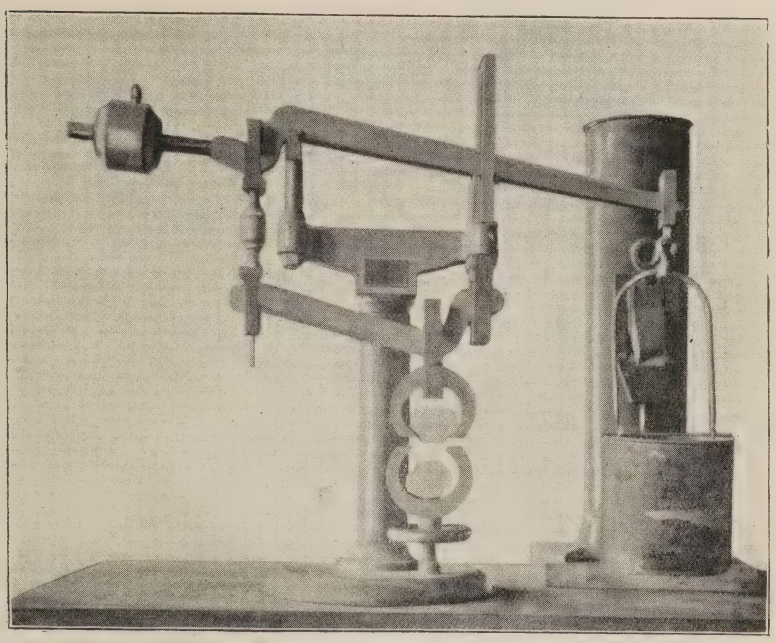

Fig. 2.

Faults in the making and drying of the briquettes are shown up by the irregular fractures. The drying of fine-grained clays without the development of very fine cracks is difficult. Such cracks cannot always be detected by inspection, but they are sources of weakness in the tensile machine and they lead to erratic results.

Description of the machine.—There are several kinds of cement testing machines available for this test. One of the simplest forms is illustrated by the photograph, Fig. 2. The essential parts of this apparatus are supported by a rigid iron

standard; a long primary lever is pivoted at its fulcrum and moves freely between guides in a vertical plane. The loading tin is supported at one end of the lever, and an adjustable weight at the opposite end acts as a counterpoise. A secondary lever moves vertically and is connected with the primary lever by a combination screw. A connecting link, swinging near the fulcrum, holds the upper breaking jaw in position; the

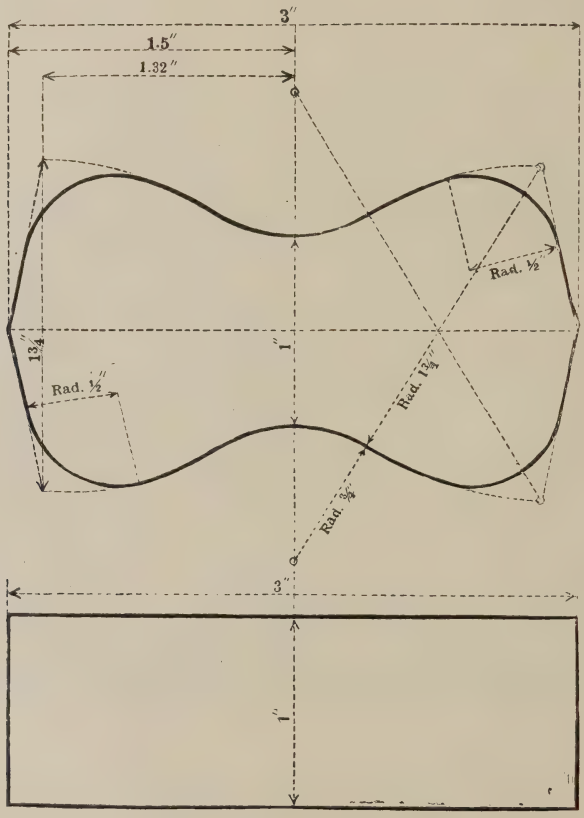

Fig. 3.

lower jaw is connected to a small hand wheel which is used to regulate the distance between the jaws. To reduce friction to a minimum all bearing surfaces work on hardened steel knife edges. When small shot is run into the loading tin the multiplying levers produce a gradually increasing tension on the test-piece in the jaws of the machine, until finally the test-piece ruptures.

Making of test-piece.—The test-piece or briquettes are made in plaster moulds and have approximately the shape and size indicated in Fig. 3 when ready for breaking. For the sake of uniformity the size indicated in the Fig. 3 may be taken. It is convenient also for clays. The manner in which the jaws grip the piece is very important, and needs careful adjustment in order to avoid shearing stresses. A suitable form of grip for clays is indicated in Fig. 4; it is modified from that recommended by The American Society for Testing

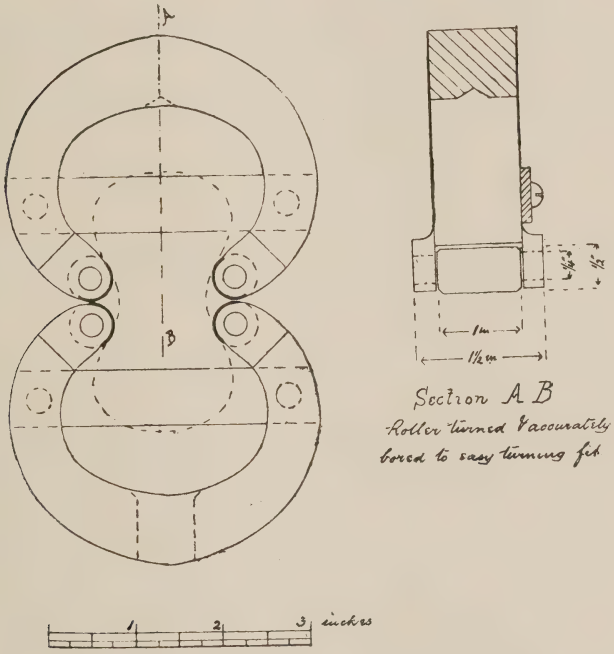

Fig. 4.

Materials in "Standard Specifications for Cement." The clay before use must be well prepared and uniform in composition and mixed with enough water to develop the maximum plasticity. The required uniformity and homogeneity is obtained by hand-wedging. The pressure used in making the test piece should be regular and uniform. Strong clays or heavily grogged mixtures require some skill in making the briquettes if concordant results are to be obtained. The test-pieces must be slowly dried in air. Irregular drying introduces internal strains, especially in close-grained clays.

The test—The primary lever is first balanced in an horizontal position, and the test-piece is placed between the two jaws. Careful centering is necessary to ensure a direct pull. The bottom jaw is lowered by turning the small hand wheel until the test-piece is lightly gripped. Leaden shot is run into the loading bucket from the metal cylinder indicated in the background of the photograph, Fig. 2. The loading must be done at a slow uniform rate, because, if added suddenly, *shock*, as distinct from the amount of *tension*, may rupture the more fragile clays. Pieces which show internal flaws about the fractured surface, and pieces which do not break within a quarter of an inch from the middle of the briquette are discarded. The cross-sectional area at surface of fracture is measured (inches) and the shot weighed (lbs.) Each machine has its own constant. The constant for the machine indicated in Fig. 2 is 50. Accordingly, the quotient,

$$\frac{\text{Weight of shot in lbs.} \times 50}{\text{Area of fracture in sq. in.}}$$

represents the tensile strength in lbs. per sq. in. The average of five or six tests should be taken for each clay.

VII.—Determination of the After-Contraction or After-Expansion of Refractory Materials.

This test is designed to find the after-contraction or after-expansion of a firebrick, *i.e.*, the approximate change in size which the brick is likely to undergo when in use at high temperatures This is sometimes called the *permanent contraction* (or expansion), but this term might then be confused with the contraction or expansion which occurs when the bricks are first fired. It is therefore recommended that the term "after-contraction" or "after-expansion" be reserved for the result of the present test. The temperature for testing recommended by the Gas Engineers' Specification is equivalent to cone 14 (1,410° C., 2,570° F.) for firebricks and material containing under 80 per cent. of silica, and cone 12 (1,350° C., 2,462° F.) for silica bricks and siliceous materials containing the equivalent of 80 per cent. or more of silica.

In making the test a rectangular piece of the material—about 3 in. in length and 1 to 2 in. in width and depth—is cut across the end and one across the middle of the sample. The sample brick is selected from the middle of the setting. The opposite ends are ground parallel on an emery or carborundum wheel, and the length measured by means of a vernier gauge reading to 0·005 cm. The piece is then fired

until the proper cone squats, and it is maintained at this temperature for 2 hours. After the cone has squatted a pyrometer is required to check the fluctuations of temperature. A gas furnace worked with an air-blast is used, with an oxidizing atmosphere. When cold the length of the test-piece is again measured and the alteration in size calculated.

The test is best done in duplicate, one piece cut from one end and one cut from the inside of the sample, and information is then obtained as to the uniformity of the firebrick.

NOTE.—The maximum contraction or expansion allowed by the Gas Engineers' Specification is: Silica bricks or siliceous material, 0·75 per cent.; retort material, 1·25 per cent.; firebricks, grade I, 1·0 per cent.; and firebricks, grade II, 1·25 per cent. The testing temperature with siliceous materials corresponds with cone 12, and with fireclay material, cone 14. A number of users consider these tests are not sufficiently severe, and that the testing temperature should be raised.

VIII.—Determination of Normal Refractoriness of Firebricks, Fireclays, &c.

A representative piece of the material is chipped or shaped into the form of a cone about 1½ in. in height. The cone is cemented to the centre of a refractory disc, about 2 in. in diameter, by means of a mixture of ground bauxite and fireclay, and Seger cones are cemented around the test-piece. The cones are chosen in the order of increasing temperatures according to the material being tested. The cones should be sloped slightly in the outward direction, so that they will not fall on to the test-piece when they melt. The disc is placed on supports on the lifting-table of a Hirsch or similar electric furnace, Fig. 5.

The initial energy is 2 or 3 kilowatts. The temperature of the furnace must be increased regularly about 50° per 5 minutes, until the first cone begins to melt. If the increase in temperature is too rapid the voltage must be increased by means of an adjustable transformer or resistance. The energy taken at high temperature varies from 7—10 kilowatts, and the voltage has to be varied according as the resistance of the furnace is high or low. The furnace works much better on an alternating than on direct current.

The cones should melt at intervals of at least 5 minutes; if two or more cones squat at nearly the same temperature the increase in temperature is too rapid, and this makes the softening point of the test-piece appear too high. The temperat which the test-piece bends over, squats, or shows signs of fusion is taken as the softening point. At this point the current is switched off, the support lowered, and the disc containing test-piece and cones plunged into cold water. This

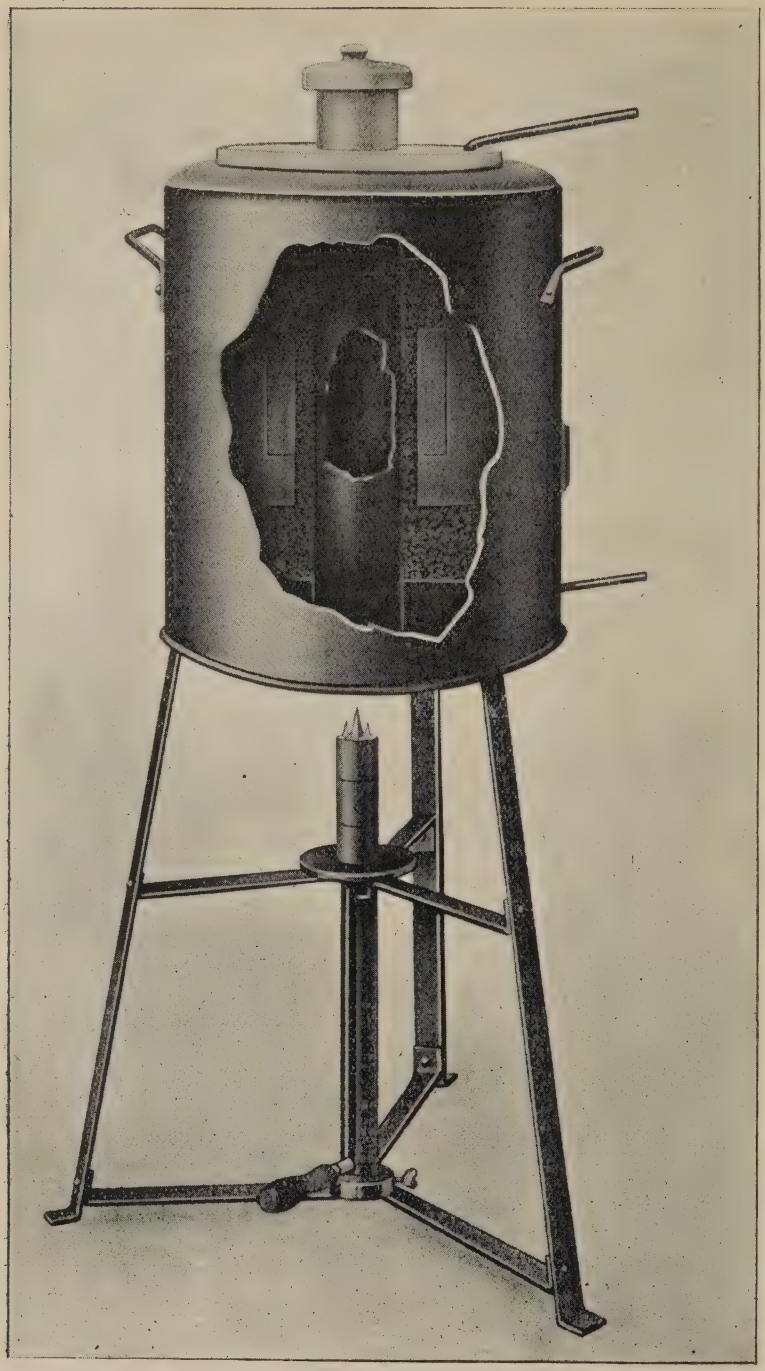

Fig. 5.

prevents the disc, etc., breaking up on cooling. The softening point of the test-piece is deduced from the cone which bent down last. The squatting temperature of a Seger cone corresponds with the temperature at which the cone bends over with the tip on a level with the base. The selection of the right cones for an unknown sample is made by successive approximation. For example, cones 20, 26, 30, 32 and 35 would be placed on a refractory disc with the clay to be tested. If cones 20 and 26 are down, and 30 to 35 are standing when the clay squats, it would be inferred that the clay squats between cones 26 and 30. In a second trial, therefore, cones 26 to 30 would be placed on the disc with the clay. The softening point of the test-piece often comes between the squatting temperature of the two cones, since the one has gone down so completely and the other one just commenced to bend. The bending temperature of Seger cones are given in the accompanying table. The comparison of the squatting temperature of refractories with a standard cone is better than expressing the results in terms of a pyrometer reading. The use of the term squatting or softening temperature is also preferable to the term melting point, since refractory materials rarely have a sharp melting point.

The following table gives the approximate squatting temperatures of Seger cones, when the furnace occupies from two to six hours to reach to the temperature in question. If the rate of rise of temperature be slower, the squatting temperatures are lower, and, if the rise be faster, the squatting temperatures are too high.

Cone No.	°C.	°F.	Cone No.	°C.	°F.	Cone No.	°C.	°F.
022	600	1112	02a	1060	1940	19	1520	2768
021	650	1202	01a	1080	1976	20	1530	2786
020	670	1238	1a	1100	2012	26	1580	2876
019	690	1274	2a	1120	2048	27	1610	2930
018	710	1310	3a	1140	2084	28	1630	2966
017	730	1346	4a	1160	2120	29	1650	3002
016	750	1382	5a	1180	2156	30	1670	3038
015a	790	1454	6a	1200	2192	31	1690	3074
014a	815	1499	7	1230	2246	32	1710	3110
013a	835	1535	8	1250	2282	33	1730	3146
012a	855	1571	9	1280	2336	34	1750	3182
011a	880	1616	10	1300	2372	35	1770	3218
010a	900	1652	11	1320	2408	36	1790	3254
09a	920	1688	12	1350	2462	37	1825	3317
08a	940	1724	13	1380	2516	38	1850	3362
07a	960	1760	14	1410	2570	39	1880	3416
06a	980	1796	15	1435	2615	40	1920	3488
05a	1000	1832	16	1460	2660	41	1960	3560
04a	1020	1868	17	1480	2696	42	2000	3632
03a	1040	1904	18	1500	2732	—	—	—

IX.—The Refractory Test Under Load.

For reasons which are obvious, it is sometimes found that a firebrick can be satisfactorily used in the masonry of a furnace at higher temperatures than the normal squatting temperature of the brick, and conversely, when the refractory is subjected to load, it is usually found that the material fails at a much lower temperature than is indicated by the normal squatting temperature. It is therefore important to test the refractory while under load.

A simple furnace for this purpose can be readily built on the same principle as that used for refractories not under load.

The one illustrated in Fig. 6 has done useful work on hundreds of samples. The diagram also explains itself.

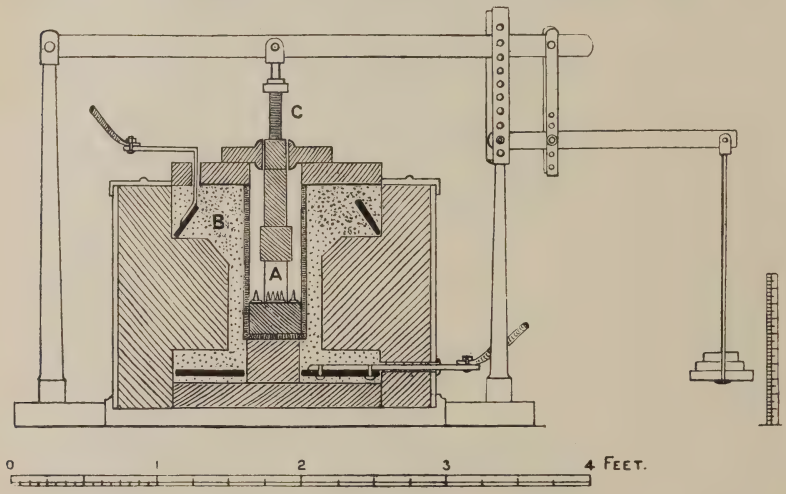

Fig. 6.

The loading of the test-piece is attained by means of a lever system. The one illustrated in the diagram gives a leverage of 12 : 1 after due allowance has been made for the weight, supports, etc.

The test-piece *A* is cut from the brick and ground to a rectangular block $3\frac{1}{2}$ in. long and 2 in. cross section. This presents a surface of 4 sq. in. to the load. The final measurements of the piece are taken with a micrometer slide gauge. Much depends upon the careful preparation of this block; if the ends are not parallel the weight will not act in a true vertical direction but tend to thrust sideways.

A solid refractory is bedded at the bottom of the inner tube of the furnace. A thin layer of powdered carborundum

is spread over the top of this basal support to prevent the sticking of the test-piece. The test-piece is placed centrally on the support so that all is quite level. Small Seger cones, arranged in series of four, are fixed on the basal support round the test-piece A cube, $2\frac{1}{4}$ in. square, made of similar material to the bottom support, is placed on top of the test-piece; this is followed by a cylinder, say, of magnesite, and finally a carbon rod *C* mounted in an iron ring. The carbon rod is attached to the lever arm in such a way that it can be moved horizontally so as to counteract any slight irregularities in supports.

If the temperature of the furnace rises too quickly, there will be too large a difference between the temperature of the interior and exterior of the test-piece, and the results will be too high, because the temperature is of necessity measured on the outside of the test-piece, and the outside is always hottest. If the temperature rises at such a rate that cone 16 squats in about 4 hours, the difference between the temperature of the interior and exterior of the test-piece is about 20°. The rate of heating is controlled by means of variable transformers and resistances, the energy used varying from 8—10 kilowatts. As the temperature of the furnace rises the thermal expansion of the brick causes the lever-arm to rise, but later the lever begins to fall. The rate at which the deformation proceeds depends on the character of the test-piece. When the squatting has reached the limit decided upon the current is switched off, the weights, lever, and supports removed and the cones observed. The test-piece is left in the furnace until it has cooled.

X.—The Thermal or Reversible Expansion of Refractories, or the Hot and Cold Sizes of Firebricks.

The change in the volume, or rather the linear dimensions, which occur when a brick is heated to the temperature of the furnace, is called the thermal or reversible expansion of the brick for that temperature, and the results are averaged to express the change in linear dimensions which occur when unit length of the brick is heated 1°. This constant is quite different from the permanent change in volume—the after-expansion or after-contraction—which occurs when an imperfectly-fired brick is heated in a furnace. The two effects may interfere with one another as indicated in our TRANSACTIONS (16, 270, 1917).

The thermal or reversible expansion is conveniently measured by Coppée's apparatus. This consists of a horizontal cathetometer, with a standard metre scale for measuring the amount of expansion, and a furnace for heating the bricks.

The cathetometer consists of a pair of sighting telescopes clamped on a metal bar which is mounted on a pivot and is capable of being revolved in a true horizontal plane. Both telescopes are fitted with two fixed cross-wires, and the right-hand telescope has also a movable vertical cross-wire attached to a delicate micrometer screw. The standard metre scale is made of invar metal graduated in centimetres and millimetres. For testing an ordinary (9 in.) firebrick a gas-blast furnace

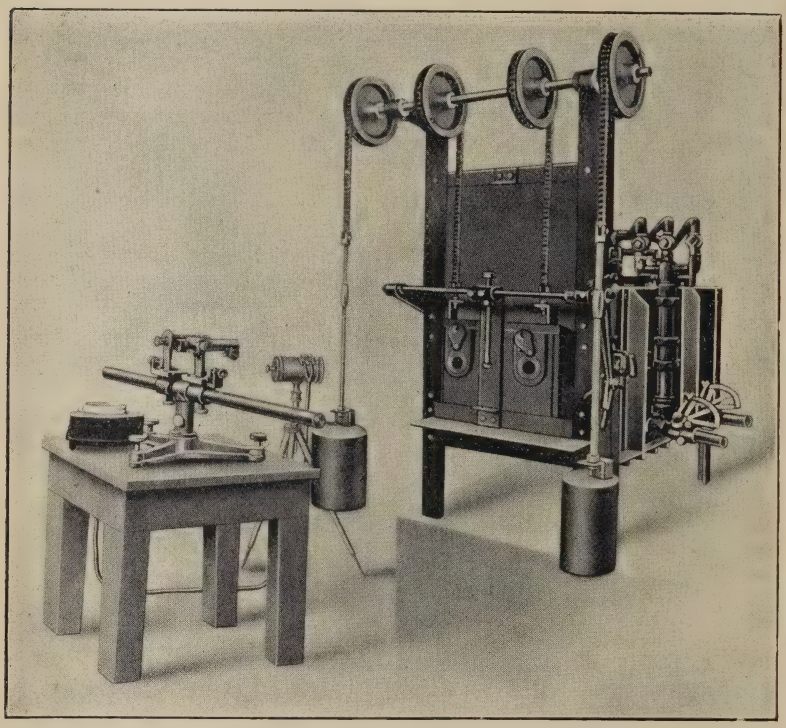

Fig. 7.

having a chamber about 24 in. long, 12 in. wide and 9 in. high, which attains a temperature of 1,300°, is suitable. Two small openings about 8 in. apart are required on either the side or door of the furnace for the purpose of focussing on the brick, Fig. 7. The temperatures can be estimated by Seger cones or measured by a Féry or other optical pyrometer.

The brick is prepared by making two saw-cuts of not less than 1 in. in depth and ½ in. from each end, on the 9 in. × 3 in.

face of the brick. A thick platinum wire, with one end finely pointed, is then fixed in each cut so that one end of each of the wires projects about $\frac{1}{4}$ in. above the top of the brick, Fig. 8.

The brick is levelled horizontally in the furnace, so that the points of the wires are visible through the holes in the door of the furnace, Fig 7. The cathetometer is placed about 5 or 6 feet from the brick, and the two telescopes are adjusted so that the cross-wires exactly coincide with the tips of the platinum wires in the bricks. The distance between the platinum points is now measured on the standard scale.

For this purpose the scale is fixed in a convenient place and at the same distance from the cathetometer as the platinum wires of the brick. One of the centimetre divisions on the scale is made to coincide exactly with the fixed cross-wires on the left-hand telescope. Suppose this division is 46 cm. and the cross-wires of the right-hand telescope lie between 67 cm. and 68 cm. The distance between the platinum points is therefore greater than 21 cm. but less than 22 cm.

Fig. 8.

The fractional part of a cm. to be added to 21 cm. is obtained by using the micrometer screw (1) to measure the number of turns necessary to move the movable cross-wires from the 67 cm. to the 68 cm. division, and (2) to measure the number of turns necessary to bring the movable cross-wires from the position of the fixed vertical cross-wire to the 67 cm. division. For example, suppose that when the vertical cross-wire coincides with the 67 cm. division, the reading on the graduated head of the micrometer is 641. The reading when the fixed and movable cross-wires are in coincidence is, say, 683. After again turning the graduated head until the 68 cm. line is reached, suppose the reading is 707. Consequently, $707-641=66$ divisions on the micrometer screw correspond to 1 cm. on the standard scale, and $683-641=42$ divisions on the micrometer screw correspond to the fraction of a centimetre to be added. Therefore the fraction is $42/66=0{\cdot}636$ cms. The distance between the platinum points is therefore 21·636 cms. The furnace is then heated up and similar readings are taken at the required temperature. This enables the difference

between the hot and cold size of the brick to be computed. The coefficient of thermal expansion or the expansion for unit length per degree (C. or F.) can also be computed. If desired the length of the brick can be plotted for a series of different temperatures.

XI.—Crushing Strength—cold.

The mechanical strength of refractory materials is one which needs consideration, since, when a firebrick is enclosed by a mass of brickwork, the weight of the superincumbent

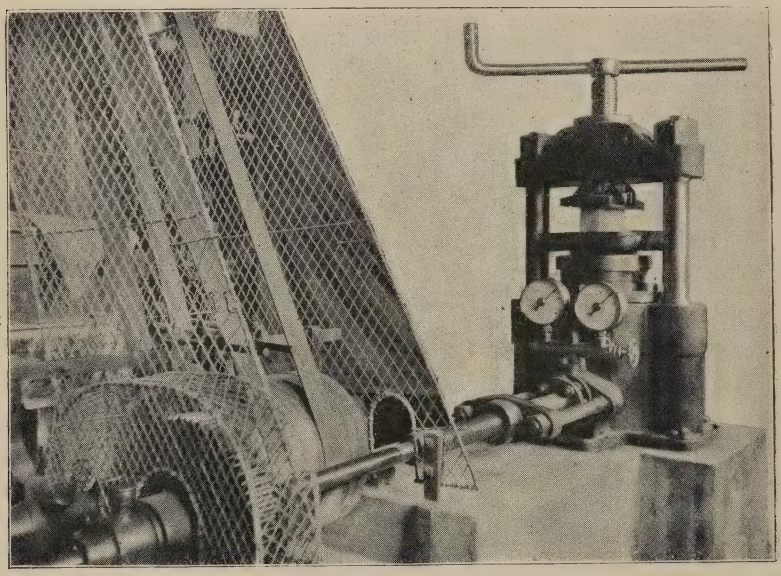

Fig. 9.

material together with the thermal expansion of the brick may produce considerable pressures. Usually, however, the crushing strength is well above general requirements.

The crushing strength test may be conveniently carried out with one of the many forms of crushing machines on the market—Weber's machine is illustrated in Fig. 9. This consists of a vertical cylinder filled with castor oil, and is provided with a movable piston and a horizontal shaft. The shaft is connected by means of gear-wheels to set of one loose and two driving pulleys. By the rotation of one of these pulleys the shaft is driven into the cylinder, and the pressure

is communicated through the oil to the piston, which is thus forced slowly upwards. By the rotation of the other driving pulley the motion of the shaft is reversed, and consequently this lowers the piston into the drum so as to obtain the maximum working space between the jaws of the press. When the horizontal shaft is worked by hand the results are not so regular, on account of the variable speed at which the test-piece is compressed; with power the speed is regular and constant.[1] The piston rises at the rate of 0·25 in. per minute. The pressure is recorded on the two gauges at the front of the press, the right hand gauge being for low pressures

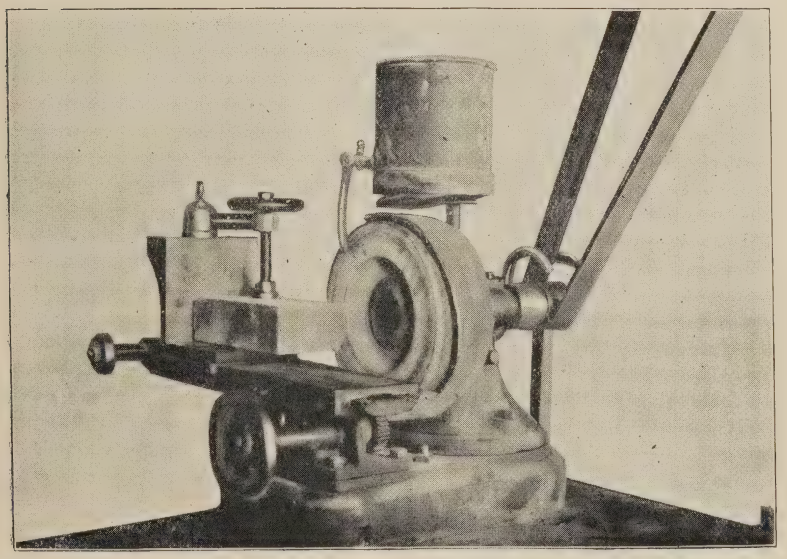

Fig. 10.

only and the other for high pressures. The brick to be tested, say a $9 \times 4\frac{1}{2} \times 3$ in. firebrick, must first have its horizontal faces ground parallel and its vertical sides at right angles to these.[2] The machine illustrated in Fig. 10 grinds the faces parallel.[3]

The brick is placed on the middle of the rectangular iron plate at the top of the piston, so that the 9 in. $\times 4\frac{1}{2}$ in. face is horizontal, and the movable iron plate on which the brick rests is levelled. The horizontal shaft is withdrawn as far as possible;

1 The power drive is a later addition not on the original machine.

2 Some prefer levelling slight irregularities with plaster of Paris or thick cardboard.

3 This machine is made by Messrs. J. Carling & Sons, Middlesborough.

the top plate is lowered on to the brick by means of the hand-screw until the gauge shows a slight pressure. The horizontal shaft is then driven to as to compress the brick. When the brick collapses the pressure is taken off, and the crushing strength read by means of the pointer on the gauge. At least five bricks should be tested to ensure a fair average result—if one or two bricks only were tested these might be unsound and consequently vitiate the result.

It will be observed that some bricks chip at the corners or edges, or develop internal cracks, some time before the maximum pressure is attained. The gauge reading is taken when the brick collapses; at the same time the indicator needle drops rapidly. To obtain concordant readings it is very important to eliminate all air bubbles from the oil in the drum. This is done by placing an iron block between the jaws of the machine and applying a high pressure for some time, occasionally opening the tap at the bottom of the cylinder. The cylinder is filled with oil by means of the small pump immediately above this tap.

The crushing pressure in lbs. per square inch is calculated by multiplying the gauge reading by 93 (this being the area of the piston in square inches) and dividing the product by the area of the brick in square inches.

EXAMPLE:—Area of brick $= 8{\cdot}85 \times 4{\cdot}4 = 38{\cdot}94$ sq. in.
Gauge reading $= 1{,}350$.

$$\text{Crushing strength} = \frac{1{,}350 \times 93}{38{\cdot}94} = 3{,}224 \text{ lbs. per sq. in.}$$

XXX.—The Deterioration of Moulds during Storage.

COMMUNICATIONS FROM THE CLAY AND POTTERY LABORATORY, STOKE-ON-TRENT.—No. 83.

By Dr. J. W. MELLOR.

IN studying particular diseases in a pottery, the ultimate object is to prevent their recurrence. Preventative remedies can be rationally applied only when we can give a clear, definite, and accurate diagnosis of the causes of a particular disease. From one point of view, the "medicine man" of a pottery is in a more difficult position than the medical practitioner. If the latter makes a wrong diagnosis, a death certificate—failure of the heart's action—written by himself, clears him completely—all men must die at least once; in pottery, however, the value of the diagnosis is judged by a more severe standard. We do try to persuade ourselves that "faults come and faults go, and no man can prevent them." This optimism, however, is obviously but a temporary expedient to prevent our being disheartened with the ignorance which is very much in evidence in our apparent helplessness before some of the technical difficulties which arise from time to time. By comparing notes at our Society's meetings we are sometimes able to get considerable help in combatting these difficulties. An account of one member's attempts to grapple with a trouble may help and stimulate another, or the account may suggest to another new facts which confirm or condemn the proposed remedy. It is with this latter object that I venture to lay before the Society my reading of the deterioration and furring of partially-used moulds during storage. Had it not been for the war, and the absence of Mr. H. Steele on active service, I should have got him to read this paper.[1]

The Composition of the Fur.

When partially-used moulds are stored they often grow a fur on certain parts of the surface, and this fur has many

H. Stee e *Trans. Cer. Soc.*, 12, 78, 1913.

analogies, in its mode of growth, and in its general characteristics, with the scum which develops in the drying of ware which has been made with water contaminated with certain soluble salts.

The following analyses of samples of scum collected in two different works were made by two students after the samples had been dried at 110°:—

	I. From an Earthenware Works	II. From a Sanitary Works
Silica	12·50 ...	12·2
Alumina and ferric oxide ...	4·50 ...	3·9
Lime	9·55 ...	24·9
Soda	29·70 ...	18·1
Sulphur trioxide	37·25 ...	18·2
Carbon dioxide and water ...	8·00 ...	24·3

It is obviously difficult to make sure that none of the plaster of Paris is included with the fur which is taken from the moulds, but the analyses do teach that the fur contains soluble salts, and that the salts are in part derived from the slight solubility of the plaster of Paris in water, and in part from the accumulation of soluble salts in the moulds.

It is certain that a large proportion of the salts in these two furs were derived from soluble salts in the clays when the moulds were in use. Assuming that sodium carbonate or silicate or a mixture of the two salts has been added to the casting slip—neglecting the soluble salts of the clay—a small proportion of these two salts will be carried into the mould each time the mould is used. A little fine clay will get into the surface pores of the plaster at the same time. The wet mould will then have in its capillary pores an aqueous solution of calcium sulphate, sodium sulphate, and possibly some sodium silicate and carbonate. There will be a redistribution of the acid radicles which introduces a difficulty in calculating the proximate composition of the fur.

How the Fur is Formed.

Precise knowledge on the exact proximate composition of the fur is fortunately not required for our present purpose, since it may be accepted as a fact that the *fur contains a considerable proportion of sodium sulphate derived in part from soluble salts in the clay, in part from the solubility of plaster of Paris in water, and in part from the decomposition of sodium carbonate and silicate by the calcium sulphate* precipitating calcium carbonate

and silicate. Chemists would perhaps represent the reactions by the equations :

$$CaSO_4 + Na_2CO_3 = Na_2SO_4 + CaCO_3$$

and

$$CaSO_4 + Na_2(SiO_3)_n = Na_2SO_4 + Ca(SiO_3)_n$$

It follows also that this fur must have worked its way from the interior to the surface of the mould much as a scum is formed on clay bodies during drying. As water works its way from the interior of the mould it carries soluble matter along the capillary pores of the mould, and, evaporating on the surface, slowly deposits the soluble matter in a crystalline form as a fur or scum.

This same phenomenon is also familiar to builders, where bricks set with mortars carrying soluble salts produce a white efflorescence or fur as they dry after wet weather has distributed the soluble salts about the pores of the bricks. When the supply of soluble salts is exhausted the bricks no longer efflorescence or scum. Floor tiles set in cement which carries soluble salts, and which is sometimes damp, may show an efflorescence as they dry; similarly, floor tiles may receive a charge of soluble salt from the use of washing soda or other soluble salts when the tiles are washed; and an efflorescence may grow on the tiles if they are dried rather slowly.

I am informed that before soluble salts were used in the casting slip the furring of moulds was not very marked, and that press moulds, if given a rest by storing in a dry place, are reputed to be improved rather than injured by storage.[1]

If the casting clay contains no soluble salts the only soluble matter in the internal water must be derived from the slight solubility of plaster of Paris in water. It is interesting to note, in passing, that plaster of Paris is much more soluble in water carrying certain substances in solution. Soluble phosphates, for instance, increase the solvent action of water on plaster, and this explains why the casting surface of moulds for bone china bodies does not last so long as for earthenware. The presence of soluble phosphates in bone-slip hastens the solution of the plaster. This rapidly erodes the surface and diminishes the life of the mould.

I believe also that casting slip, thinned by the addition of a mixture of an alkaline carbonate and silicate, exerts a greater solvent action on the moulds than when the alkaline salts are absent; these moulds, however, have a longer life than when ordinary slip is used. This is because the mould

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W. Emery, *Trans. Cer. Soc.*, **9**, 170, 1910.

really absorbs less water (or rather, solution) per cast than when ordinary slip is used.

The Rotting of Stored Moulds.

Not only do moulds during storage develop a fur or scum, but they sometimes become "rotten," and readily disintegrate when they are again brought into use. This seems to me a consequence of a remarkable property of growing crystals. If a crystal of alum, growing in a solution of the same salt, be loaded with say a kilogram weight, it is able to lift the weight upwards about half a millimetre. This fact was demonstrated by G. F. Becker and A. L. Day[1] in 1905, and contradicted later by W. Bruhns and W. Mecklenburg in 1913; but the later work of Becker and Day, in 1916, left no doubt about the existence of a very remarkable linear force exerted by growing crystals which is altogether independent of the volume-expansion exhibited during crystallization by, say, the setting of plaster of Paris, or by the freezing of water. Both forces are of considerable magnitude and importance.

Suppose a crystal, fed with an appropriate solution, be growing in an open crack in a wall, and further, suppose the crystal touches both sides of the crack, pressure is exerted tending to separate the walls, and this notwithstanding the fact that the crystal is quite free to grow in other directions. If the solution of sodium sulphate be put in an earthenware vessel slightly crazed on the inside, the solution will work its way into a porous body, and in a couple of weeks the piece will be "rotten," it will lose its characteristic ring and shatter to pieces with a slight tap. This is an experiment which creates surprise when seen for the first time, because the sodium sulphate is so very searching and plays havoc with the body.

As I have said, the linear force of growing crystals is not quite the same as that powerful force which is also exerted when many substances crystallize or freeze *en masse*. Water-pipes which burst, and bricks, roofing tiles, and flower pots which shatter during the thaw after freezing weather are an eloquent testimony to the force which liquids exert when they solidify. The standard test for the liability of roofing tiles, flower pots, etc., to rupture in this way, is to soak the vessel with water and expose it alternately to frost and thaw a number of times. Nearly a century ago, with the same object, it was proposed to test bricks by dipping them for half-an-hour in a

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1 G. F. Becker and A. L. Day, *Proc Washington Acad. Sciences*, **7**, 283, 1905; *Journ. Geol.*, **24**, 313, 1916; W. Bruhns and W. Mecklenburg, *Jahresber. Niedersäch Geol. Ver.*, Hanover, **6**, 92, 1913.

saturated solution of a salt, and allowing them to dry in air, and thus imitate in a simple way the effects produced by water freezing in the pores of the brick. Various salts have been proposed for the purpose. In 1828, J. Brard, M. Vicat and H. de Thury[1] investigated the most suitable salts for the purpose, and came to the conclusion that an aqueous solution of sodium sulphate—Glauber's salt—is most suitable. This happens to the very salt which is probably doing a similar work in the pores of plaster moulds when partially-dried moulds are subsequently dried slowly in the store room.

These facts seem to me to furnish an adequate explanation how imperfectly-dried moulds in a dry store room, or dried moulds in a damp store room, or in a damp part of a store room, lose their tenacity and deteriorate towards rottenness with keeping. If this explanation of the action is correct moisture is absolutely necessary for the deterioration, since there is no evidence of the growth of dry crystals.

If damp moulds are rapidly dried the crystals will be small; if slowly dried they will be larger, and, if very slowly dried, larger still. The growth of fur is evidence of dampness or moisture, since moisture is a necessary vehicle for the transport of food in the form of soluble salts to the growing crystal.

Preventative Remedies.

The precautions necessary to prevent the deterioration of moulds during storage are now obvious:—

(1) Do not store the moulds until they are thoroughly dried—not partially dried, but thoroughly dried—throughout their whole mass.

(2) The moulds should be dried as rapidly as practicable so as to keep the crystals small, when they exert the least rending power.

(3) The store room should be dry, and if practicable warm, so as to prevent the condensation of moisture on the surface during muggy weather. Surface condensation is hardly so serious as the storing of partially-dried moulds, since it might produce furring without interfering much with the internal state.

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[1] J. Brard, M. Vicat, M. Billaudel, M. Conrad and H. de Thury, *Ann. Chim. Phys.* (2), **38**, 160, 170, 175, 181, 182, 189, 1828; J. W. Cobb, *Journ. Soc. Chem. Ind.*, **26**, 390, 1907.

XXXI.—A Method for the Graphic Determination of Quaternary Mixtures.

COMMUNICATIONS FROM THE CLAY AND POTTERY LABORATORY, STOKE-ON-TRENT.—No. 84.

By HORACE S. NEWMAN.

IT is probably advisable to first state the reasons for putting forward this method. The triangular diagram has been used to show graphically mixtures of three substances, but it has certain limitation if an endeavour is made to use it for determining mixtures of four substances, such as are commonly used in earthenware and similar bodies. Dr. J. W. Mellor says in his *Higher Mathematics* (London, 119, 1905) that "the composition of quaternary mixtures has been graphically represented by the perpendicular distance of a point from the four sides of a square," and this is an attempt to utilize this principle in our work on body mixtures.

If body mixtures are determined by the triangle method as quartz, felspar and clay we obtain a comparison that is lacking, from the point of view that the potter uses in compounding his bodies, ball clay, china clay, Cornish stone and flint instead of quartz, felspar and clay. If the triangle is used, then, before the bodies or trials are made up, a relationship between the quantities of ball and china clays must be arbitrarily fixed for the series; also the felspar, quartz and clay must be calculated into the materials used, from the ultimate analyses of these, and this many potters are unable to do.

Suppose a series of trials is thus made, using two of ball clay to one of china clay, we obtain one set of comparisons, but, obviously to fully study the effects of all combinations of these materials, we must construct several series of mixtures each having different proportions of ball and china clays.

In order to overcome this proportioning of clays, to avoid the calculations and to consider the mixtures from the standpoint of the materials as used and bought by the potter, the following method has suggested itself from the use of squared paper.

A square is drawn and divided along its top side *A—B* as shown in Fig. 1, and lines are drawn from these points to the base *C—D* parallel with the sides *A—D* and *B—C*. All points on the lines so obtained represent that amount of the material *A* indicated by the figures at the top of the lines.

Similarly the side *B—C* is divided and lines drawn parallel to *A—B*, these lines representing amounts of *B* as shown by the figures against the lines. The points of intersection of the lines give mixtures of these two materials *A* and *B* in the proportions indicated by the values of the lines. Now if another square be drawn and divided as shown in Fig. 2, similar to Fig. 1, but proceeding from the other two corners, we obtain mixtures of *C* and *D* for the same points as in

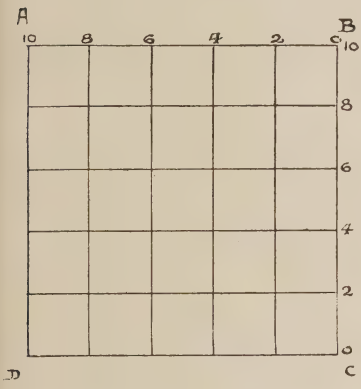

Fig. 1.

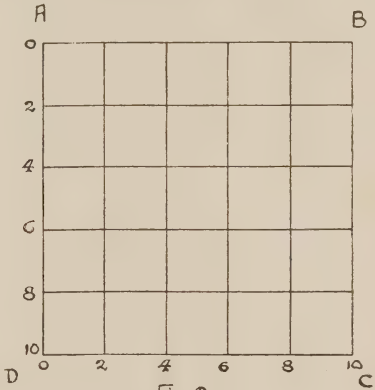

Fig. 2.

Fig. 1. Obviously all that now remains to be done is to combine the two figures and we have points representing various mixtures of the four materials *A*, *B*, *C* and *D*.

In determining the mixtures for trials it may at first be found more convenient to use the two figures independently as shown in Figs. 1 and 2, but after a little practice, if the two squares are combined to form one as they should be, the quantities of each material can be easily read off, especially if, to facilitate matters, different coloured inks be adopted to write in against each point on a key diagram the quantities of that material which the colour used represents.

It will be found that the figures for each point total to 20 or some multiple thereof, and to convert these figures to percentages it is only necessary to multiply them by some obvious constant.

The table shows a set of mixtures extracted from the diagram, Fig. 3, and converted to percentages.

Having obtained a set of trials from these figures a comparison of the effects of differing proportions of the various materials can now be readily studied graphically as in the use of the triangle diagram. The great point is that in the square diagram the comparisons are based upon the actual materials in the state the potter uses them, whereas, if the

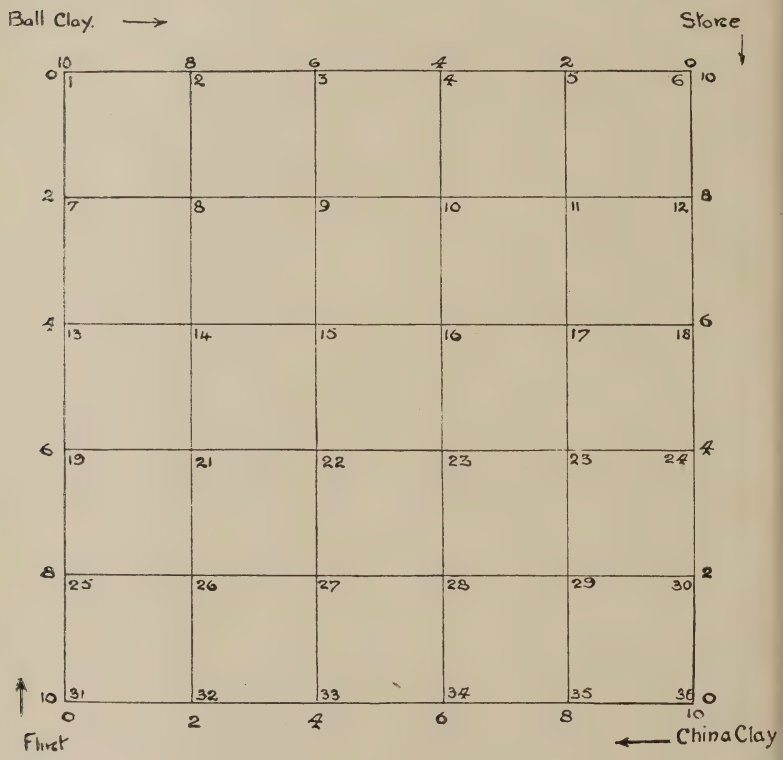

Fig 3.

triangle diagram is used for quaternary mixtures, the comparisons are based upon calculated composition from the ultimate analysis of the materials. From this point of view this method may prove of considerable use to potters who do not obtain, or calculate from, ultimate analyses of the materials they use. Further, a comparison of the graphic results on the square diagram against the same mixtures calculated to quartz, felspar and clay, and plotted on to a triangle may bring

out some interesting and useful results. Unfortunately, like many others, this method has its limitations, which are:—

(1) No mixtures having more than 50 per cent. of any one material can be obtained from the square.

(2) No mixture of the materials represented by the two opposite corners only are shown, *i.e.*, no point indicating 50 per cent. of *A* and *C* or of *B* and *D*.

For mixtures of materials such as are used in earthenware bodies, however, the second of these limitations does not present any considerable trouble, for, if ball clay oppose china clay and flint oppose stone, we have paired those materials which we know are not used by themselves.

The first limitation is rather unfortunate, but even with this failing the method opens up possibilities.

A set of trials is being prepared to the tables given, and it is hoped to present the results obtained on the square diagram and also on the triangle diagram in the next TRANSACTIONS.

TABLE OF MIXTURES

Point Number	Ball Clay	China Clay	Stone	Flint
1	50	0	50	0
2	40	10	50	0
3	30	20	50	0
4	20	30	50	0
5	10	40	50	0
6	0	50	50	0
7	50	0	40	10
8	40	10	40	10
9	30	20	40	10
10	20	30	40	10
11	10	40	40	10
12	0	50	40	10
13	50	0	30	20
14	40	10	30	20
15	30	20	30	20
16	20	30	30	20
17	10	40	30	20
18	0	50	30	20
19	50	0	20	30
20	40	10	20	30
21	30	20	20	30
22	20	30	20	30
23	10	40	20	30
24	0	50	20	30
25	50	0	10	40
26	40	10	10	40
27	30	20	10	40
28	20	30	10	40
29	10	40	10	40
30	0	50	10	40
31	50	0	0	50
32	40	10	0	50
33	30	20	0	50
34	20	30	0	50
35	10	40	0	50
36	0	50	0	50

XXXII.—The Dissociation of Salt.

COMMUNICATIONS FROM THE CLAY AND POTTERY LABORATORY, STOKE-ON-TRENT.—No. 85.

By H. V. THOMPSON, M.A.

IT is a matter of common knowledge that salt is decomposed by water at high temperature with the formation of sodium hydroxide and hydrochloric acid,[1] but no results seem to have been published which throw any light on the amount of salt decomposed by water under any given set of conditions.

The importance of the subject will be at once recognised in connection (*a*) with salt glazing, and (*b*) with the action of the salt in coal on refractories. Dr. J. W. Mellor suggested an investigation of the dissociation of salt in steam from the point of view of physical chemistry, since the results may have an important influence in guiding along right lines the theory which may develop on the action of salt on silicates.

The following paper records the results obtained in a series of experiments made to determine the hydrolysis of salt in the neighbourhood of 1,100° C.

1.—*Apparatus.*

The furnace consisted of a porcelain cylinder 12·5 cm. long, 6 cm. external diameter, threaded externally and wound with nickel-chromium resistance wire, the wiring being coated with fireclay cement. Specially prepared clay discs, pierced for the reception of the pyrometer and reaction tube were cemented into the ends of the furnace. The furnace was placed concentrically inside a large earthenware cylinder and the intervening space tightly packed with calcined kieselguhr, which was cemented down at either end.

A platinum, platinum-rhodium thermocouple in conjunction with a standardized millivoltmeter served to record the temperatures, which could be adjusted at will by a variable resistance in the main heating circuit.

The reactions were carried out in a platinum tube 24·8 cms. long, 1·25 cms. internal diameter at the rear end, tapering

1 *cf.* P. Gorgeu, *Compt. Rend.*, **102**, 1108, and 1164, 1886; S. English and W. E. S. Turner, *Proc. Chem. Soc.*, **106**, 162, 1914.

gradually from this end to an internal diameter of 0·6 cms. at the far end: the tube was bellied out 7·5 cms. from the rear end so as to form a receptacle for the salt.

The tube was firmly fixed through the holes in the above-mentioned clay discs by means of asbestos corks, and asbestos corks were also used to make connection between the ends of the tube and other pieces of the apparatus *(vide infra)*.

The furnace and tube thus assembled were mounted on a wooden stand.

Preliminary experiments clearly showed that when a stream of air saturated with water vapour, or when dry steam was passed through the tube and over the surface of molten salt in the reservoir, the amount of hydrochloric acid, produced by hydrolysis, was far too small to be estimated with any degree of accuracy.

This state of affairs naturally arises from the fact that the products resulting from the hydrolysis of the salt recombine in the cooler portions of the tube, and, moreover, this reversal of the system is accelerated by rapid cooling and not retarded, as is the case in many gaseous systems.

Furthermore, had it been possible to estimate the amount of hydrochloric acid liberated in the reaction the result would not have given the actual amount of salt decomposed, but only the net amount, since the fine mist of sodium hydroxide resulting from the hydrolysis would be swept towards the cool end of the tube and would there recombine to a greater or less extent with the hydrochloric acid as this gas was swept through the tube.

Consequently it was necessary to adopt another line of attack.

It is a well-established fact that at and above its melting point sodium chloride has an appreciable vapour pressure[2], and Prof. J. W. Cobb has estimated that at 800° C. the rate of volatilization of salt is about 6·9 per cent. per hour[3] under the *particular* conditions of his experiment. Hence, when salt is heated to a temperature above its melting point in a tube through which a stream of air is passing, the salt vapour will be carried forward and deposited on the cooler portions of the tube.

The amount of salt so deposited will depend upon the vapour pressure of the salt, that is, upon its temperature and also upon the rate at which the amount of air flows through the tube.

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2 *cf.* W. Nernst, *Zeit. Elektrochem.*, **9**, 622, 1903.

3 *The Gas World (Coking Section)*, April 1, 1916, p. 11.

If, however, a stream of air is saturated with water vapour and then passed through the tube, the water vapour coming into contact with the molten salt will hydrolyse it, and the products of hydrolysis, together with the salt vapour, will be swept along the tube until a point is reached where the vapour is deposited and (as the preliminary experiments showed) where the sodium hydroxide and hydrochloric acid recombine.

Hence, if the amount of salt deposited between the reservoir and the far end of the tube be determined in each case, the difference between the two values will give the actual amount of salt which has been hydrolysed by the water vapour in the stream of air.

2.—*Experimental Details.*

All the experiments were carried out in the neighbourhood of 1,110° C. At first the temperature of the furnace was controlled by the method described by Dr. J. W. Mellor in *Trans. Eng. Cer. Soc.* (7, 114, 1909), but in conformity with the observations therein recorded the temperature variations at 1,110° C. were too great for accurate control. Ultimately it was found that by careful regulation and adjustment of the variable resistance it was possible to maintain the temperature of the furnace constant to within ±12° C. The reservoir in the reaction-tube was filled with pure salt, great care being taken that no salt was scattered on the walls of the tube on the far side of the reservoir. Any particles of salt adhering to the rear end walls were removed with a brush, and the reservoir was then heated in a Teclu burner until the salt was just molten.

After the salt had solidified in the reservoir, the tube was fixed in the furnace as previously mentioned, an asbestos cork carrying the inlet tube was then cemented into the rear end of the platinum tube and the far end was similarly connected to the absorption train, which consisted of two small conical flasks, each containing 50 c.c. of distilled water. It is doubtful whether the absorption flasks serve any useful purpose when a stream of dry air is passing through the tube, since all the salt seems to be deposited long before the mouth of the tube is reached, but with moist air a small amount of salt is invariably carried forward into the absorption flasks by the condensed steam.

When the furnace had reached the requisite temperature a current of dry or moist air was admitted, according to circumstances, into the tube from an aspirator at an average rate of 2 litres per hour, the velocity being controlled by a tap specially adapted for fine adjustment.

The air was dried by passing it through a train of vessels charged respectively with concentrated sulphuric acid, calcium chloride, soda lime and calcium chloride, whereas in the experiments with moist air the air was passed through a couple of Woulff's bottles, one-third full of water. The temperature of saturation was taken by two thermometers, one placed in the water and the other in the stream of moist air as it issued from the bottle.

The experiments were usually conducted for a period of six hours, after which the current of air was turned off and the reaction-tube allowed to cool down slowly in the furnace.

The tube was then removed from the furnace and the forward portion of it, between the reservoir and the far end, was repeatedly washed with warm water until free from chlorides. These washings and the water and washings from the absorption flasks were evaporated to small bulk, filtered into a platinum dish, evaporated to dryness, ignited and weighed as sodium chloride.

The results of the experiments are embodied in the following table and are to a large extent self-explanatory. In the experiments with dry air the amount of salt vapour carried forward by the current varied between ·0515 and ·0602 gms. per litre. Whereas when the air was saturated with water vapour the quantity rose to ·0715 to ·0846 gms. per litre—the averages for both series of experiments being ·0554 gms. and ·0782 gms. per litre respectively.

Experiment No.	Mean Temperature of Furnace	Weight of Salt carried over	Vol. of Air passed through	Temperature of Saturation of Air	Weight of Salt carried over per Litre of Air
1	1114°C	0·7513 grms.	12·48 litres	—	$6·020 \times 10^{-2}$
2	1113°C	0·6214 ,,	12·0 ,,	—	5·178 ,,
3	1110°C	0·6893 ,,	12·0 ,,	—	5·744 ,,
4	1110°C	0·6785 ,,	12·0 ,,	—	5·654 ,,
5	1107°C	0·6227 ,,	12·1 ,,	—	5·146 ,,
6	1110°C	0·6667 ,,	12·1 ,,	—	5·510 ,,
Mean	1110·7°C	0·6716 ,,	12·11 ,,	—	5·545 ,,
1	1118°C	0·9083 ,,	12·1 ,,	23·0°C	7·507 ,,
2	1114°C	0·8960 ,,	12·1 ,,	22·1°C	7·405 ,,
3	1111°C	0·9900 ,,	12·0 ,,	22·0°C	8·250 ,,
4	1113°C	1·0236 ,,	12·1 ,,	22·8°C	8·460 ,,
5	1117°C	0·9903 ,,	12·0 ,,	22·0°C	8·252 ,,
6	1111°C	0·8656 ,,	12·1 ,,	22·2°C	7·154 ,,
7	1119°C	0·8636 ,,	12·0 ,,	21·8°C	7·197 ,,
8	1115°C	0·9951 ,,	12·0 ,,	17·8°C	8·292 ,,
Mean	1114·6°C	0·9416 ,,	12·05 ,,	21·7°C	7·814 ,,

The increase due to the presence of water vapour is approximately 40 per cent. and represents the amount of salt hydrolysed by the water in the stream of air. Now the mean temperature of saturation was 21·7° C., at which temperature a litre of air, when fully saturated, contains ·01895 gms. of water, consequently ·01895 gms. of water have decomposed ·02269 gms. of salt. Hence 1 gm. molecule of water decomposes 0·37 (0·3690) gm.-molecules of salt at 1,113° C. under the particular experimental conditions.

Further experiments were made to ascertain the effect of a stream of air, charged with water and salt vapour, on some of the more important constituents of clays, viz.: silica, alumina and iron (ferric) oxide.

The apparatus was arranged in all details as in the previous experiments, but a platinum tray carrying the materials under investigation was inserted immediately in front of the reservoir of salt.

3.—(*a*) *Silica.*

Selected chips of quartz from the Isle of Man were exposed to the action of salt and water vapour for periods varying up to six hours, at approximately 1,100° C. Four independent experiments were made in this way, and in all cases the quartz had more or less lost its glassy appearance, being of an opaque white colour, while the sharp edges and rough faces had become smooth, but the reaction was only superficial.

Experiments were then made to determine, if possible, the composition of the glaze on the quartz. Specimens of the quartz chips, as removed from the tube, were well washed with hot water and the washings tested gravimetrically for silica, but no trace could be detected, hence no water-soluble silicate had been produced. The washed quartz was then digested with 35 c.c. of water and 10 c.c. of concentrated hydrochloric acid and the silica and sodium oxide estimated in the washings.

Three experiments gave the following results, expressed in gm.-molecules of the two oxides:—

Sodium Oxide		Silica
1·000	...	1·113
1·000	...	0·890
1·000	...	1·016

the mean value being 1·000 Na_2O to 1·023 SiO_2, which may be taken as representing equi-molecular proportions. It is perhaps of interest to note that L. Barringer[4] gives a com-

[4] L. Barringer, *Trans. Amer. Cer. Soc.*, 4, 211, 1902.

position for salt glaze in which, if all the metallic oxides be expressed in equivalent quantities of sodium oxide, the ratio is 1·000 Na_2O to 0·911 SiO_2.

The mechanism of the reaction is probably as follows:—The current of air carries forward the salt vapour, which impinges on the quartz and adheres to it, covering the surface with a thin film of molten salt, and at the same time the salt is hydrolysed by the water vapour with the formation of a sodium silicate insoluble in water.

The insolubility of the silicate in water is apparently due to the high temperature to which it has been exposed and is analogous to the insolubility of strongly ignited alumina or iron oxide in hydrochloric acid.

Two experiments were made in which quartz at a temperature of 1,165° C. was exposed to salt vapour and dry air for 13½ and 14½ hours respectively. In spite of the prolonged heat treatment the quartz was markedly less attacked than when it had had a much shorter period of heating in a current of moist air.

4.—(b) Iron (Ferric) Oxide.

Commercial ferric oxide was heated for 12 hours at 1,169° C.; much salt had volatilized over and the ferric oxide had been converted into magnetic iron oxide, Fe_3O_4, whilst numerous black shining crystals had formed in the mass. A small trace of ferric chloride had also been formed, as on emptying the contents of the reaction tube some minute white patches were noted, which turned yellow on exposure to air.

Another specimen of iron oxide, heated continuously for 21 hours at 1,157° C., was not noticeably more crystalline than the previous sample.

In order to determine if the black crystals were formed by the crystallization of the magnetic iron oxide in the presence of salt, ferric oxide was mixed with excess of salt and heated for 12 hours in the full blast of a Teclu burner. On dissolving out the cake and washing free from chlorides a mass of black crystals remained. Half of these crystals were ground, well mixed with salt, and again heated for 5½ hours. 0·9977 gms. of the second crop of crystals on analysis gave 0·0252 gms. SiO_2, 0·7036 gms. Fe and 0·2689 gms. O_2 (by difference). The molecular ratio between the iron and oxygen is exactly as 3 : 4, hence the crystals were Fe_3O_4.

A duplicate experiment in which ferric oxide was heated without the addition of salt showed that it was only partially converted into magnetic iron oxide, and that no crystals of this oxide were formed, consequently the crystallization must be due solely to the presence of salt.

5.—(c) *Alumina.*

Alumina on similar heat treatment became coated with a layer of fused salt, at times several mm. thick, with an unaltered core of alumina. The fused mass of salt and unchanged alumina was digested with water and the filtrate and washings made up to 100 c.c. The amount of chloride in an aliquot part was estimated and calculated as sodium chloride per 100 c.c.; the alumina and sodium as sodium chloride were next determined in the remaining portion of the filtrate. The difference between the two quantities of sodium chloride per 100 c.c. of the filtrate is proportional to the amount of sodium oxide in combination with the alumina in the same volume of the filtrate.

Two experiments gave 1 Al_2O_3 to 4·19 and 4·76 Na_2O respectively, which may or may not indicate the formation of a sodium aluminate of the empirical composition $2Al_2O_3,9Na_2O$.

In all the above experiments with quartz and alumina the action was only very slight and apparently quite superficial, while in the case of ferric oxide the salt merely acted as a medium for the crystallization of the magnetic iron oxide, which is normally produced by heating the first oxide. However, under industrial conditions, the constituents of a clay or brick are exposed continuously for months, or even years, to the combined action of salt and water vapour, and it is not to be expected that a similar amount of attack will be apparent in laboratory experiments of a few hours duration. Also the combined action of salt and water vapour on a highly complex body, such as a clay, is not strictly comparable to their action on the separate constituents of a clay.

6.—(d) *Clays.*

A few tentative experiments were made with clays, and although no attempt was made to study in detail the nature of the changes produced, it was apparent that a more deeply seated action had ensued than in the case of the pure constituents. Moreover, the effect seemed to be greater as the iron content in the clays increased, and in the case of a highly ferruginous earth incipient fusion was discernible.

In conclusion, I am much indebted to Dr. Mellor, not only for suggesting this research, but for much help throughout the course of it.

DISCUSSION.

Mr. W. J. Rees:—This paper is of particular interest as the results obtained by Mr. Thompson have an important bearing

on the corrosion of coke-oven linings. It will be exceedingly useful if the author will continue his experimental work on clays so that quantitative information with regard to the action of salt vapour on clay materials may be available. It would also be valuable if the experiments could be carried out in a controlled atmosphere at a temperature of about 1,000° C., and also at 1,250° C. to 1,300° C. It would be of interest to know if in his experiments Mr. Thompson obtained any indication of the presence of free chlorine. De Sanderval (*Comptes Rend.*, 1893, 116, 641) showed that when a porous earthenware tube is heated in an external atmosphere containing vapourized salt, free chlorine is found in the interior of the tube and the outer surface is glazed by the combination of the sodium with the silica, etc. After a time no more chlorine makes its way through owing to a stoppage of the pores by this glazing action. The latter phenomenon was obviated by using a tube of other material such as carbon and working in an atmosphere of carbon dioxide. The indications are therefore that the attack on clay materials, as in the corrosion of coke-oven linings for instance, may be due both to sodium oxide and to free chlorine. The direct formation of ferric chloride by the action of chlorine and its subsequent oxidation to ferric oxide, either by access of air when discharging the oven or from the penetration of excess oxygen from the combustion flues, would give rise to some of the phenomena one sees in the examination of corroded coke-oven linings. The amplification of this experimental work in the directions indicated should furnish results of considerable interest.

Prof. W. G. FEARNSIDES, as one whose Department was endeavouring to help South Yorkshire and Derbyshire coke makers to meet their salt troubles, expressed his appreciation of the immediate usefulness of the physico-chemical data published for the first time in Mr. Thompson's paper.

It was not realized by many people how very important the "salty coal" problem is to the British nation. Though, considering the comparative smallness of its total area, Great Britain is a country wonderfully endowed by Nature with great reserves of many varieties of mineral fuels, the quantity of good coking coal contained in her coalfields is not by any means greater than her prospective future needs. Before very long it may therefore become necessary to reserve for coke-making all the coal which will produce a satisfactory coke, and in many districts very salty coking coals will have to be sent to the ovens.

Speaking of the distribution of salt among coals of Yorkshire and Derbyshire, Prof. Fearnsides commented upon the

notable increase in the proportion of salt as the depth from which the coals are obtained increases. All coals won in this district from depths greater than 350 yards below sea-level carry brine which is almost completely saturated with common salt. Possibly the reason that the Durham coke-ovens are comparatively free from salt troubles is that in that district the maximum depth at which the coal-bearing measures occur, even in the very centre of the coalfield, does not by much exceed 300 yards below sea-level. The maximum depth from which the saltless coking coals of South Wales are mined is also inconsiderable.

In dealing with the chemical action of salt vapours upon the walls of coke-ovens, it should not be forgotten that salts other than common salt (sodium chloride) and also water-vapour and sulphur dioxide exert a marked effect, though by reason of its quantitative predominance and the vigour of its reactions one could agree that the behaviour of sodium chloride well deserves its pride of place as the first salt to be examined.

Mr. Thompson had made mention of the part played by iron salts when heated in association with sodium chloride vapours and organic matter. In this connection some observations upon the action of coal-gas upon certain Northamptonshire ironstones may be of interest. Wet, or at least damp ironstone of the blue-stone type, is often calcined with coking coal as fuel out in the open in large heaps or clamps. As the coal near the outside of the heaps burns, the coal inside the heap is converted into coke and smoke and vapours escape by more or less well-defined passages between the blocks of stone, and take fire at or near the upper surface of the heap. A deposit of beautifully crystalline hæmatite is formed as a sublimate, covering all the surfaces fairly thickly and cementing together the neighbouring ironstone blocks, just where these vapours meet the air. From this it would seem to follow that in the course of this calcining process some volatile organo-iron compound had been formed, and after passing as a gas for a distance of several yards through the heap, had been decomposed when that gas met the air and burnt.

In Yorkshire coke-ovens, wherever salt troubles are rampant, there is generally a zone to which bright red hæmatite is sublimed. This hæmatite zone generally occurs at a distance from half an inch to an inch within the coke-oven brick away from the actual coke-contact surface of the walls. Whether this hæmatite has been produced in the same manner as that which we found in abundance cementing the heaps of ironstone in Northamptonshire, *i.e.*, by the volatilization of some organo-iron compound along with the coke-oven gas, or in the form

of ferric chloride as Mr. Thompson's experiments might suggest, does not yet appear, and the matter requires and deserves to be investigated further. In any case it seems probable that since the iron oxide sublimate produced in coke-oven walls has been subjected to maximum temperatures similar to those under which Mr. Thompson carried out his experiments the chemical condition of the iron oxide ought to be the same in the two cases. Having reason to know that ironstone sublimate and the coke-oven wall product is in part transparent, and has optical properties quite similar to those of the mineral hæmatite, the speaker suggested that Mr. Thompson should investigate under the microscope the physical properties of the sublimate of iron oxide which he described, and offered the suggestion that his sublimed iron oxide is also a translucent blood-red hæmatite.

Mr. F. ROWLINSON:—It is well known that in the manufacture of electrodes for electrical steel furnaces we have used saline cokes of some description. At the high temperature of the arc this salt volatilized, and very seriously attacked the roof of the furnace. In conjunction with the iron and lime from the bath, little stalactites were formed on the roof, interfering greatly with its strength and refractoriness.

There was a paper dealing with this subject a few weeks ago in the *Jour. Soc. Chem. Ind.* (1918, 37, 123 T), and the conclusions there arrived at were very similar to Mr. Thompson's.

Another point occurring to me in connection with the volatilization of salt is the proposal put forward by Mr. Kenneth Chance, after experiments carried out at the instance of the Ministry of Munitions, to add sodium chloride to the charge in blast furnaces. The idea is to recover in the flue dust that potassium chloride which now goes into the slag. Chance states very definitely that no deleterious action on the furnace lining is to be expected. I am taking this with a grain of salt; opinion on the subject appears to be about equally divided, some ironmasters stating that the glaze formed on the bricks is protective in its action, others that it tends to disintegrate them. I should like Mr. Thompson's opinion on this point—whether the addition of salt to a blast furnace charge is likely to have a deleterious effect on a furnace lining.

Mr. H. V. THOMPSON stated, in reply, that he had not tested for free chlorine, and that there were no indications of its formation during the course of any of the experiments.

In regard to the saltiness of coals it had been suggested that this was due in some cases to the infiltration of saline water from the Triassic deposits. This supposition would satisfactorily explain the sharp line of demarcation between salty and non-saline coals, which was particularly noticeable in certain parts of the North Staffordshire coalfield; however, direct geological evidence was required in order to support this view.

Since the communication of the paper further investigation had shown that the iron oxide mentioned therein contained a very small proportion of translucent blood-red hæmatite, but that the main bulk corresponded in chemical, crystallographic and physical properties to magnetic iron oxide.

The addition of salt to a blast furnace charge was a matter which required careful investigation, but in the absence of positive evidence there was no reason to suppose that the lining of a blast furnace would be more resistant to the action of salt than the walls of a coke-oven.

XXXIII.—The Bending of Easy-fired Ware.

COMMUNICATIONS FROM THE CLAY AND POTTERY LABORATORY, STOKE-ON-TRENT.—No. 86.

By BERNARD MOORE.

THE great loss we have through crooked glost, sinking of saggar bottoms and covering bats, and the collapse of saggar sides and firebricks under load, shows that the subject of my paper is a most important one. I shall try to point out the chief factors that influence this bending, for if we can once grasp the reason we shall have a much better chance of finding a remedy. Some of the problems are rather hard to understand. For instance, most of us know that easy-fired biscuit bends more readily in the glost than harder fired. I am speaking now of a pottery body of the ordinary earthenware type. [Examples shown.]

At first sight it might be thought that the reverse should take place. I shall show the reason why the hard-fired stands better than easy-fired, but I shall also show a type of body which will bend more readily when it has a harder biscuit fire.

In order that the views I intend to put forward may be understood it is essential that you should have a clear idea of what takes place in a pottery body when it is being fired. Dr. Mellor, in his "Notes on the Pottery Industry," has most ably covered most of the ground; you will find the information in the three or four papers in that work.

A study of these with the various microscopic sections will be most helpful, and they are amongst the most valuable contributions to ceramic literature. I do not propose to go over this ground again, but I propose to supplement it, and I want, for the purpose of this paper, in the first instance to simplify the point of view of a pottery body a little, and to consider it as consisting of an infusible framework and a fusible flux. I shall deal with the complications later.

Pottery Bodies consist of Fusible Matrix and Infusible Framework.

I use the words fusible and infusible in the sense that they are so at the particular temperature at which the body

is fired. The fusible flux I shall call the matrix, adopting the word used by Dr. Mellor in the papers to which I have referred.

With this proviso this definition seems to me to cover all pottery bodies.

The ultimate analysis does not give us full information as to the type of body that is examined. An earthenware and a hard porcelain might have an identical chemical composition.

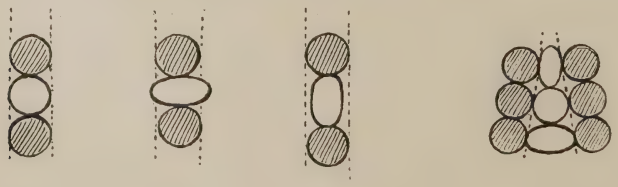
The lower types of body, such as earthenware, are generally low in this matrix and high in infusible framework.

The porcelain types, on the other hand, are high in the fusible matrix and lower in the infusible framework. The matrix in the fired body, however, differs often very much in the two types. In the earthenware type it is generally much softer, *i.e.*, more fusible than in the porcelain types and for this reason. During the firing of a pottery body which consists, say, of a flux of any kind and a clay, as soon as the flux melts it re-acts with and gradually dissolves the more infusible material. In this way this flux or matrix is growing and generally becoming harder and harder until finally it is saturated, and when this point is reached the maximum contraction has generally taken place. (See Mellor.)

During this firing the surface tension of the matrix draws the other materials together, the matrix trying to occupy the smallest space it can. Where there are no other forces helping or retarding this action the contraction is regular. When, however, there is any outside influence the contraction may be irregular. I will show one or two examples of this. I have fired two pieces of pyrometer tube made of the same body and from the same slip. One I have suspended during the firing, the other I have placed on the end.

Marks were placed on the two tubes 8 ins. apart. The suspended tube was under tension, the other under compression. There is a very marked difference in the contraction.

The weight of that portion of the tube between the marks is only 2 ozs., but even this small difference has a marked influence on the contraction. Think of the body as consisting of a fusible matrix and an infusible framework.



(*a*) (*b*) (*c*) (*d*)

Fig. 1.

In Fig 1 the shaded circles represent, diagrammatically, the infusible particles, and the clear circles the matrix.

In (*a*) contraction takes place without interference.
In (*b*) „ „ under compression.
In (*c*) „ „ under tension.

My next example shows clearly what happens when easy-fired ware bends. This example is very interesting. I have fired three Bullers' rings without any weight, side by side with three on which I placed a weight of about 9 lbs. As I expected, the weighted ones have not contracted as much as the others.

I have prepared strips $10 \times 2 \times \frac{3}{8}$ in. thick and fired them [samples shown].

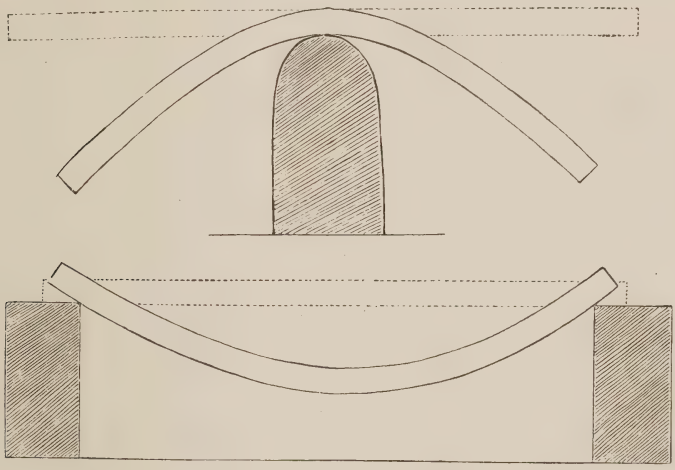


Fig. 2.

The contraction of the surface of these is most remarkable; it varies from 12 per cent. to 2 per cent. only. The normal contraction of the body is about 7 per cent.

The inside middle portion contracts 12 per cent. (this is under compression).
The outside middle portion contracts only 2 per cent. (this is under tension).
The mean inside is 10·3 per cent.
The mean outside is 5·7 per cent.

Fig. 1 (*d*) may be taken to represent diagrammatically the contraction of the strip, the top row of circles corresponding

to the inside middle portion, and the bottom row to the outside middle portion.

This is what takes place in many instances not only with earthenware bodies but with many firebricks, saggars, etc. It is often not a breaking down of the whole substance but a softening and compression of the matrix. You will readily grasp that it is much easier to compress the matrix when the full contraction has not taken place, because there is less friction against the infusible particles in the framework and of course much less tensile strength.

This explains why it is so inadvisable to put much weight on easy-fired saggars, and why the practice of confining the use of easy-fired saggars to the tops of the bungs has become general.

Formation of Eutectic.

You will notice that a short time ago I said that the matrix generally becomes more and more infusible as it dissolves more and more of the ingredients. This is not always the case, for eutectics, or something analogous to eutectics, may be formed.

The formation of the matrix is not such a simple process as might be supposed. Felspar is the most common flux, and this melts below 1,200° C.; it may, however, combine with another material, which although itself infusible at that temperature forms a eutectic which melts at a lower temperature. The addition of about 20 per cent. silica, for instance, lowers the melting point of felspar nearly 100°, and certain mixtures of clay, felspar and lime have an even lower melting point.

In the pages of our TRANSACTIONS there are numerous examples of the effect of fine grinding on the speed of vitrification by Mellor, Heath and others, but there are other influences at work.

A body that has been slop-mixed fuses much more rapidly than one that has been dry-mixed. If a body is composed of various ingredients a eutectic is more likely to be formed quickly if the ingredients forming this eutectic are ground together. If clay, felspar, flint, and lime were ground separately and then mixed in the ordinary way and lawned, it is quite certain there would be numerous groups of each of these materials clumped together, and although they were each finely ground they might react as if they were roughly ground.

You must remember that the apertures of the lawns used to mix a pottery body are enormously larger than the finest fraction: by averaging the fine fraction it must be at least ten times as large.

It is very important indeed not to confuse early vitrification of this matrix with rapid vitrification. An early and steady vitrification may be of great advantage because it may bring about the proper contraction and make satisfactory ware at a lower temperature, that is at a temperature at which the framework will not deform, and this will give the fireman a wider margin. If, on the other hand, the early stages are abnormally slow, then the rapid vitrification at the end makes a successful firing much more difficult.

A parallel example is furnished in the firing of an oven. How often when a fault is manifestly the result of too rapid firing one is told that it cannot be so for the oven was fired for, say, 80 hours, when 70 is the usual time. Little or no work might have been done in the first 50 hours. So it is with a flux. It is no use considering a flux a slow vitrifier if most of the work is done at the end.

In earthenware types of body, therefore, I think it is sound practice to mix and grind together those materials which we wish the matrix to be composed of. I think, for instance, that in many cases it is better practice to grind any lime added to the body with the stone rather than the flint. I think also it explains why it is more difficult to pot with dry white stone than it is with purple.

Character of Framework.

There is little doubt that the infusible framework I have spoken of consists mainly of what was clay. In an ordinary pottery body I am of opinion that there is another matrix which plays a very important part; it is intimately mixed with the infusible framework, the foundation of which is the clay. I shall call this the matrix of the framework.

We know that all clays have more or less fusible bases in them which in rational analyses we calculate as felspar. I am not prepared to say what they are, but we know that they are which plays a very important part; it is intimately mixed with with the clay. The conditions, therefore, are favourable for early vitrification, and we see examples of this in the ball clays, vitrifiable fireclays, and strong china clays.

Nearly all clays, and particularly ball clays, have extremely finely divided flux mixed in them, and being so intimately mixed it serves to vitrify the clay. It is this which gives strength and ring to a body; it explains why potters like a strong clay. At first sight it might be thought that by slightly increasing the stone a weak white clay could always be used. It is not so, however, for no matter how carefully the slip is prepared

you would not get the intimate mixing which obtains in a natural clay.

It is this matrix of the framework which produces the so-called bending point of fireclays under load. We know of clays which vitrify at 1,000° or less, but which do not melt till they reach cone 33 or more. These, however, might not stand under load.

It must be remembered that many of our pottery bodies are almost plastic at a high temperature. I have seen a badly placed piece of bone china turned inside out without being broken. If the matrix is very fluid it will bend easily, if it is viscous it will be more likely to stand.

The type of body which will bend more readily if it has been hard-fired is the type which has practically no framework, but has been turned by firing into a hard matrix. A Seger cone fired to, say, 1 cone less than its bending point is an example.

Nothing has been more frequently emphasized than that fine grinding lowers the melting point of mixtures. Common sense must be used in interpreting this, and you must be careful to fully grasp what it means, and not think that it applies where it does not.

The air which is between the particles of very finely ground flux prevents it from forming a clear glass unless it is very fluid. A solid piece of raw felspar fuses to a clear glass without bubbles. Finely ground spar would be white and opaque at the same temperature. Similar remarks apply in the manufacture of quartz glass.

(*a*) A homogeneous frit may completely melt more easily when rough ground.

(*b*) When you have a mixture of a flux and another material such as flint or clay forming a pottery body, fine grinding of the infusible part may prevent bending in the biscuit and not produce it. This point is very important and is very little understood. The principle that fine grinding increases the chemical action is sound, but some read something into the law which is not there. They overlook some of the conditions. I will give an example:—

If you mix, say, felspar with a roughly ground material it may not have time to dissolve it, because it is rough or the particles are clumped together. The matrix therefore is softer and more fluid and bends more easily in the biscuit than it would have done had all the materials been ground together.

A parian body of, say, 60 felspar and 40 clay, if simply mixed and lawned, will not stand so well as if the clay and felspar had been ground together. In the first case the clay has clumped and the felspar has not had time to dissolve it and to make the hard glass-like body which is necessary for success.

The potting practice of grinding all the materials of a parian body together is justified; it is always a pleasure to find instances of this, for there is no doubt that these practices sometimes represent natural facts to a greater extent than science is yet competent to explain.

The practical point I wish to draw attention to is that we have some control on what takes place by the way we mix.

Summary.

A glost oven often for a few minutes in the hottest part almost touches the biscuit temperature, and if contraction has not taken place a compression increases this contraction and a tension retards it.

Manufacturers have little control on the matrix of the framework except by selecting suitable clays, but they have very great control on the matrix of the body. Points for consideration are:—

(*a*) Texture—fineness of grinding.

(*b*) Method of mixing. One type of body may require different treatment to another.

(*c*) We must not expect to get full results from fine grinding if we allow the fine particles to clump together.

(*d*) If a body bends we may be able to produce a more viscous matrix, often without changing the composition.

(*e*) Great importance of an early and steady vitrification of the matrix—it gives the fireman more margin.

(*f*) Full contraction must be brought about in the first fire if a body has to stand compression or tension at a high temperature during a second fire.

I have had the great advantage of discussing many of these points with Dr. Mellor. I wish to thank Mr. Emery and Mr. Wilfrid Bakewell for carrying out some experiments for me.

DISCUSSION.

Mr. C. E. Ramsden:—The effect of superimposed weight in reducing the longitudinal contraction of the circular trial pieces shown corresponds with the practice in firing bungs of tiles placed about ten high, the lower ones showing less contraction. Presumably the same consideration applies to pieces of terra-cotta or sanitary ware, sometimes made two or three inches thick. There must be considerable pressure on

the lower particles. I should like to ask Mr. Moore if he would agree with this. The grinding of the whole of the body materials together would appear to be conducive to the production of homogeneous ware, but even if partially carried out would involve changes in practice, especially as regards size of moulds, time and temperature of firing, etc.

There is generally inadequate mixing of the slip in spite of it being agitated, lawned, pumped, etc. In bad cases this is observable in the cakes of clay from the filter press.

The author's remark that, contrary to expectations, the shortcomings of a weak white clay cannot be balanced by an increase of stone is in agreement with the failure of attempts to imitate the effects of Cornwall stone by synthesis, using mixtures of felspar and china clay.

Bearing on the remark that, when roughly ground, frit will often melt more easily, it is interesting to recall that in the vitreous enamelling of metals, such as copper, the enameller rejects the finer material, using only the larger particles of the frit, which give a quickly fusible glass.

I notice that on one of the strips, which was supported at the ends during firing, the surface contraction is recorded at the ends as 8·75 per cent. at the top and 6·62 per cent. at the bottom, which leads me to ask whether the contraction at the ends has been influenced by the hold of the supports?

Mr. A. G. RICHARDSON:—Many of the troubles indicated by the trials illustrate the effects of imperfect mixing. It is a question whether sufficient care is taken in the process of slip-making. The time allowed for agitation and the speed varies very much. There should be some kind of standard for guidance. Thorough agitation on some satisfactory basis, and more care in carrying out the operations, would give better results. Mr. Moore has demonstrated all his points.

Mr. BERNARD MOORE:—In reply to Mr. Ramsden's last question I did all I could to prevent any holding by the supports, and certainly there was no holding together in the pieces supported only at the middle. This difference in contraction between points not far away has a great influence on dunting.

I do not always advocate the grinding of all the ingredients of earthenware together, for that might spoil the ware, but of those parts which form the matrix. If lime is used in the body it should be ground with stone rather than with flint; 3 per cent. of lime gives very much earlier vitrification when mixed with stone than when mixed with flint. Dry white stone gives

a better colour than hard purple, but it is a very slow starter and offers more difficulty in the production of a sound, reliable body.

I omitted to show trials consisting of felspar with 5, 10, 15 and 20 per cent. respectively of ball clay added. They were finely ground and mixed dry, and after firing looked like stoneware of poor colour. Other trials made of similar materials slopped together gave a better colour and seemed quite good stoneware. All these trials were fired side by side up to 1,200° C. The fusible matrix in the first set had not dissolved much of the other material, and the trials showed a bad colour. Similar trials were made with the additions of 5, 10, 15 and 20 per cent. respectively of flint. These showed better vitrification than the corresponding trials without the flint.

XXXIV.—Effect of Load on the Refractoriness of Firebricks, etc.

COMMUNICATIONS FROM THE CLAY AND POTTERY LABORATORY, STOKE-ON-TRENT.—No. 87.

By J. W. MELLOR and W. EMERY.

THE present report is a continuation of that presented in 1916.[1] In the tests on fireclays described in that report, disturbing factors, due to variations in the grain size, in the method of manufacture, and in the methods of firing, were largely eliminated by making the test cylinders by the same process, preparing the materials in the same manner, and conducting the test under approximately the same conditions. The two important empirical facts then established were:—

1.—The refractoriness of a fireclay under load diminishes as the load increases in accord with the rule:—Refractoriness $= Ce^{-kW}$, where C denotes the refractoriness not under load, W is the load in lbs. per square inch, and k is a constant characteristic of each fireclay. Every fireclay has its own load constant k when determined under these conditions. The values of k ranged from 0·0030 to 0·0116 for a series of typical fireclays, and the higher the value of k, the more sensitive the refractoriness of the clay to load.

2.—The sensitiveness of a fireclay to load is greater the greater the "alumina" content of the clay, and the sensitiveness of a fireclay to load is less the greater the "silica" content of the clay. This empirical rule has been confirmed by a great number of further tests, although the exact connection has not been established. The rule has no reference to firebricks as usually made, since the rule was tested only with materials made up in a definite way.

In extending the investigation to bricks, it was necessary to devise a larger furnace, and after a number of failures the furnace illustrated in Fig. 1 was found to give excellent results. It is fairly simple in construction, and is based on the furnace used in the preceding tests, but adapted to larger pieces. It

[1] *Trans. Cer. Soc.*, 15, p. 117.

therefore requires very little explanation. The loading of the test-piece is attained by means of a lever system. The one illustrated in the diagram gives a leverage of 12 : 1, after which due allowance has to be made for the weight of the supports, etc.

The refractoriness under load is determined in the following manner:—The test-piece is cut from the brick and ground to a rectangular block $3\frac{1}{2}$ in. long and 2 in. cross section. This presents a surface of 4 sq. in. to the load. The final measurements of the piece are taken with micrometer slide gauge. Much depends upon the careful preparation of this block. If the ends are not parallel, the weight will not act in a true vertical direction, but tend to thrust sideways.

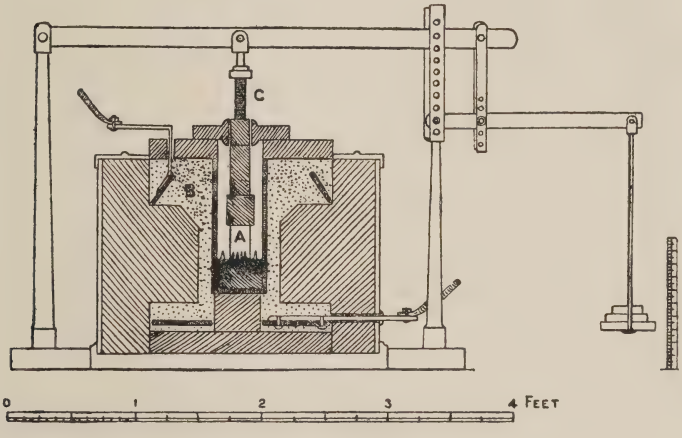


Fig. 1. Furnace.

A solid refractory support is bedded at the bottom of the inner tube of the furnace. A thin layer of powdered carborundum is spread over the top of this basal support to prevent the sticking of the test-piece. The test-piece is placed centrally on the support, so that all is quite level. Small Seger cones, arranged in a series of four, are fixed on the basal support round the test-piece. A cube $2\frac{1}{4}$ in. square, made of similar material to the bottom support, is placed on top of the test-piece. This is followed by a cylinder, say, magnesite—and finally a carbon rod C mounted on an iron ring. The carbon rod is attached to the lever arm in such a way that it can be moved horizontally, so as to counteract any slight irregularities in the supports.

If the temperature rises at such a rate that cone 16 squats in about 4 hours, the difference in the temperature of the interior

and exterior of the test-piece is about 20°. The rate of heating is controlled by means of variable transformers and resistances. The current used varies from 8 to 10 K.W. As the temperature of the furnace rises, the thermal expansion of the brick causes the lever arm at first to rise, and later on the lever begins to fall. The rate at which the deformation proceeds depends on the character of the test-piece. When the squatting has reached the limit decided upon, the current is switched off, the weights, lever, and supports removed, and the cones observed. The test-piece is left in the furnace until its temperature has cooled.

The first measurements were directed towards finding the relation between the temperature in the interior and exterior of the test-piece. Briquettes of various sizes were made, some with one and some with two holes, so that pyrometers could be inserted from above the furnace through holes in the supports, and so into the test briquettes. It will be obvious that fallacious results could be very easily obtained if the interior of the badly conducting briquette is at an appreciably higher temperature than the exterior. A. V. Bleininger and G. H. Brown[1] examined this question and plotted curves for their furnace, which indicated that after 3 or 4 hours' heating the temperatures inside and outside the brick are nearly identical. We have repeated these measurements for the furnace illustrated in Fig. 2, and find that there is over 100° difference between the interior and exterior of the full-size brick on a 3 to 4 hours' heating, and also on a 12 to 13 hours' heating. This is illustrated by the four pyrometer charts reproduced in Figs. 2 to 5. The pyrometers were checked by means of a reversing switch. This proved that the difference in the recorded temperatures is not due to a constant difference in the readings of the two instruments, but to a real temperature difference in the interior and exterior of the bricks. The need for keeping the interior and exterior of the test-piece at as nearly the same temperature as possible limits the size of the test-piece. If the test-piece be not greater than 1 sq. in. in sectional area there are difficulties with pieces containing coarse grog, for such pieces are unduly weak mechanically. This is confirmed by the failure to obtain constant results under such conditions. Test-pieces of 4 sq. in. section area were finally used. With these the temperature can be maintained so that the interior is from 20° to 50° less than the exterior temperature on a 4 hours' heating. This determines the chief error of the experiments. The results indicated in the tables therefore require this correction factor.

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1 A. V. Bleininger and G. H. Brown, *Trans. Amer. Cer. Soc.*, **12**, 337, 1910.

TABLE I—REFRACTORINESS OF COMMERCIAL FIRE-BRICKS.

LOAD 50 LBS. PER SQUARE INCH.

		Seger Cones		
Mark	Type of Brick	No Load	Loaded	Remarks
B1	Very hard	32-33	19-20	Deformed steadily
B2	Ditto	32-33	16-17	Ditto
C2	Hard	30-31	13-14	Steady at start, collapsed suddenly later
C3	Ditto	29-30	13-14	Ditto
D	Soft, poor texture ..	20	14-15	Ditto
E1	Medium fired	30-31	16	Deformed steadily up to end
E2	Ditto	31-32	16	Ditto
F	Very hard	30	14-15	Steady early on, collapsed later
G1	Hard	30	16	Steadily deformed all the way
G2	Ditto	29-30	15-16	Ditto
H	Ditto	29-30	15-16	Ditto
J	Hard, badly cored in centre	31	15-16	Steady at first, quicker towards finish
N1	Hard	28-29	16	Deformed steadily
N2	Very hard	30-31	15-16	Ditto
O	Hard	30	17	Deformed very uniformly and slowly
P	Soft, fine texture	30-31	14-15	Ditto
Q	Very hard, good texture	32-33	20-26	Ditto
R	Very hard	32-33	16-17	Ditto
S	Hard, poor texture ..	26	14	Ditto
A2	Rather soft	30-31	15	Ditto

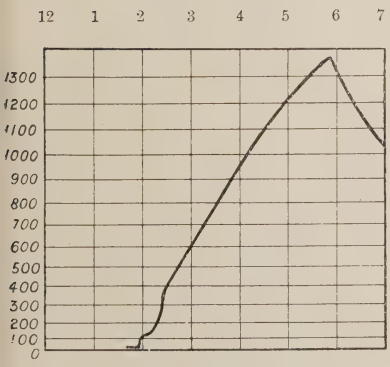

Fig. 2. Outside Pyrometer.

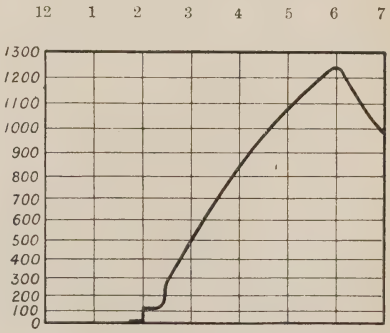

Fig. 3. Inside Pyrometer.

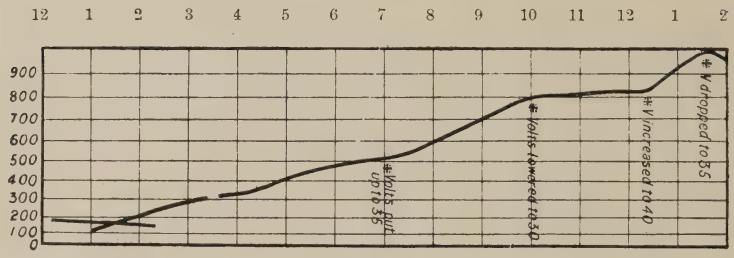

Fig. 4. Outside Pyrometer.

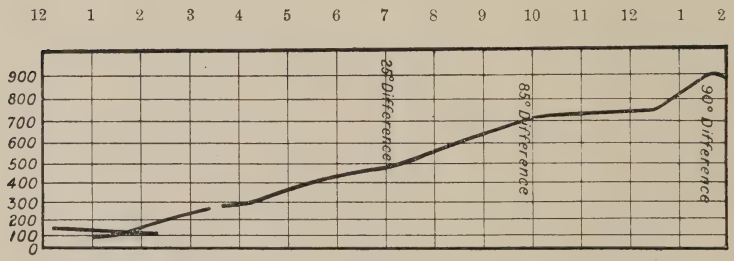

Fig. 5. Inside Pyrometer.

The flux or matrix which binds the constituents of the firebrick together is quite different in the grog from what it is in the clay, even though the grog is made from the very same clay as is subsequently used for making the bricks. This is due to the fact that in the grog the fluxes of the clay have dissolved so much of the less fusible constituents that it is less fusible and more viscous than the flux in the original clay. When the clay and grog are fired together the flux of the clay softens at a much lower temperature than that of the grog, so that the fluxes of the clay and of the grog do their work independently.

Firebricks with coarse grog are liable to break down mechanically by a diagonal shear, whereas with finer grog the collapse appears as if the actual fusion temperature is reduced, for the test-pieces bulge as was the case with the fireclays indicated in the previous report. During the burning of the firebrick the clay does not get so good a grip of coarse grog as with fine grog. See a later report on the crushing strength.

We are of the opinion that if a single specification test is to be prescribed for refractoriness under load, 50 lbs. per square inch is too great. A smaller load would give clays with a higher softening temperature a better chance. The most

instructive test would be a curve showing the behaviour of the refractory unloaded, and with at least two different loads; but if one test is to be presented, a load of 25 or 30 lbs. per square inch will probably suffice.

TABLE II—REFRACTORINESS OF COMMERCIAL SILICA BRICKS. LOAD 50 LBS. PER SQUARE INCH.

Mark	Type of Brick	Seger Cones		Remarks
		No Load	Loaded	
A1	Siliceous brick, rough red and white siliceous grog	31-32	19-20	Steady at start, collapsed suddenly later
K	Soft, red, fine even grain	29	3	Collapsed without any deformation
L1	Hard, reddish, fine even grain	30-31	15	Collapsed after slight deformation
L2	Very hard, rough grog	32-33	30-31	Ditto
M	Soft, white, fine even grain	30	14-15	Deformed steadily
C1	Soft, white, medium even grain	33-34	17	Deformed very quickly

In general, the silica bricks stand up under load very much better than firebricks made from fireclays; but the finer grained silica bricks do not stand under load so well as the coarser grained silica bricks. Indeed, very fine grained silica bricks show as large a difference between the normal refractoriness and the refractoriness under load as bricks made from fireclays.

TABLE III—REFRACTORINESS OF COMMERCIAL SPECIAL REFRACTORIES. LOAD 50 LBS. PER SQUARE INCH.

Mark	Type of Brick	Seger Cones		Remarks
		No Load	Loaded	
T	Magnesite	> 40	18	Deformed slightly, then collapsed
V	Chromite (German)	> 40	13-14	Ditto
Z	Zirconia	> 40	15-16	Gradual from start to finish. With a load of 25 lbs, per sq. in., the bricks squatted between cones 26 and 27; and with a load of 75 lbs. per sq. in., between cones 14 and 15

The analyses of the magnesite and zirconia bricks are as follows:

	Magnesite Brick	Zirconia Brick
Silica (SiO_2) ...	5 22	10·91
Titanic oxide (TiO_2) ...	—	1·25
Alumina (Al_2O_3)	1·57	3·92
Ferric Oxide (Fe_2O_3) ...	0·75	4·11
Manganese oxide (MnO) ...	—	under 0·01
Magnesia (MgO)	88·48	0·21
Lime (CaO)	2·96	0·16
Potash (K_2O)	0 03	0·36
Soda (Na_2O)	0·25	0·38
Zirconium Oxide (ZrO_2) ...	—	75·95
Loss on ignition	0·03	2·40

The results shown in Tables I, II, and III were obtained with firebricks as supplied by manufacturers, and they may be taken as representative of the refractoriness of firebrick without load and when under a load of 50 lbs. per square inch.

Firebricks under load seem to break down in one of two ways. In one type of collapse (*fusion collapse*) the firebricks gradually give way as the temperature rises, until finally the piece collapses. This behaviour is typical of aluminous and zirconia bricks. The breaking-down temperature indicated in the tables is not a definite temperature, but rather an arbitrary range of temperature during which the brick has sunk (say) 1 in. In the second type of collapse (*mechanical collapse*) the firebrick may show symptoms of a gradual deformation; but the characteristic feature is a more or less abrupt collapse. This is typical of silica and siliceous bricks, and, to a less degree, of magnesite and chromite bricks, although a sufficient number of varieties of the latter have not been determined to give the same confidence in making general statements.

The effects produced are exceedingly complex, and they are affected by many factors other than composition. The texture is one of the most important, as emphasized in a paper by one of us some time back,[1] but even here there are cross results. As a first approximation, a firebrick can be regarded as a mixture of certain materials which are difficult to fuse with a more fusible constituent. During the firing of the brick the more fusible constituents form a matrix binding the other materials together. The matrix, particularly in the coarser grained materials, seems to determine the refractoriness under load. The red firebrick K collapses under load at cone 3, when the same brick under no load does not collapse until

[1] J. W. Mellor, *Trans. Cer. Soc.*, **16**, 40, 1916.

cone 29—nearly 500° C. higher. In this case the matrix suddenly lost its binding power under the load. A firebrick fortified with silica grog may stand up under no load better than the brick without this grog; but with the load the ground mass gives way without being fortified by the grog.

When this investigation was planned some time before the war, when Mr. Bywater was taking an active part in our work, most of us anticipated that firebricks would show variations which would enable us to specify a minimum refractoriness which firebricks should stand under a definite load; and this view was afterwards confirmed by the specification of a load in the States. So far as our examination goes, the refractoriness under load is very much more complex than was at first supposed. Specimen No. K does exceedingly good work in the building of the settings of gas-retorts—in fact, it has long been a favourite. It collapses mechanically at cone 3, approximately 1,140° C. (or 2,084° Fahr.) under a load of 50 lbs. per square inch. This seems an exceedingly bad result. We think it is very fortunate that we have been very cautious in specifying tests, or a blunder would have been made.

How comes it that a brick can possess a refractoriness under load which is far lower than the temperature at which the brick is doing good work in a furnace? A brick was made with three borings, respectively 7, 5, and 4 in. deep, and pyrometers were fitted into the holes, illustrated in Fig. 6.

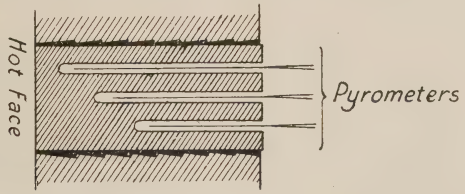

Fig. 6.

In the steady state, when the face of the brick is at 1,000° C., the temperature of the interior is:—

	Hot Face	3½ in. away	4¾ in. away	6¼ in. away
Temp.	1,000°	720°	570°	350°

Under normal conditions, the temperature of the interior would probably be hotter than this; but in any case, it follows that although the face of the firebrick may be soft under a load, further inwards the temperature is lower; and if the brick is not inclined to spall, the softening of the face would in most cases do good, not harm. The brick in the masonry is also supported differently from a test-piece heated in a furnace, for it is not free to bulge except on one side.

In view of our ignorance as to the particular methods of manufacture of the firebricks indicated in Tables I to III, a few series of firebricks were made up in a known way, from clays known to be good, and also from those known to be of inferior quality. These bricks were made up in a uniform manner on a brickworks. It was hoped that the variations introduced would bring out definite information. The analyses of the raw materials are indicated in Table IV. The grain sizes of the different materials supplied to us are shown in Table V. It would have been better to thoroughly disintegrate the clays into their ultimate granules by various well-known artifices; but the results would not then have met the purpose of the present work, viz.: to find the effects produced under ordinary working conditions. The surface factors are calculated by the formula[1]

$$\text{Surface factor} = 2{\cdot}4\left(\frac{W_1}{d_1}+\frac{W_2}{d_2}+\frac{W_3}{d_3}+\frac{W_4}{d_4}\right)$$

where d_1, d_2, . . . denote the average diameters of the fractions; and W_1, W_2, . . . the percentage weights for the particular fractions in question,

$$\text{Surface factor} = 2{\cdot}4\left(\frac{W_1}{1{\cdot}76}+\frac{W_2}{0{\cdot}44}+\frac{W_3}{0{\cdot}14}+\frac{W_4}{0{\cdot}066}\right)$$

Grog was made from the raw clay by mixing the clay with water, moulding approximately 8 in. cubes, drying, and firing some to cone 10, some to cone 1. The fired blocks were ground and graded as follows:—

Fine ..	..	Passed through a 16s riddle.
Medium ..	..	Remained on a 16s riddle, passed through an 8s.
Coarse ..	..	Remained on an 8s riddle, passed through a 4s.

The grog and clay were re-combined in the following proportions indicated in Table VI. The materials were proportioned at the laboratory, and mixed on the Cobridge Brickworks by shovels, and, after a good soaking, they were again mixed by treading. This treatment ensures that the original grading of the grog is not altered, as might have occurred had the mixing been done in the pan.

The A B series were hand-made and allowed to stiffen by partial drying. They were then re-pressed in Johnson's hand press; the M2-4-5-6 series were made in the press without the preliminary hand moulding. The bricks were then slowly dried, fired to cone 02 in a Newcastle kiln, and afterwards to cone 10 in a down-draught kiln. Otherwise, the bricks were made under ordinary working conditions with regular workmen under Mr. J. A. Audley's supervision. The results are indicated in Table VII.

1 J. W. Mellor, *Trans. Cer. Soc.*, **9**, 94, 1910.

TABLE IV—ANALYSES OF RAW MATERIALS, BY MR. C. EDWARDS.

	O	D	V	S	Z
Silica (SiO_2)	53 84	61·88	55·90	49·55	51·24
Titanic Oxide (TiO_2)... ..	1·32	1·14	1·47	1·67	1·39
Alumina (Al_2O_3)	25 73	22·37	27·74	30·30	28·06
Feric Oxide (Fe_2O_3)	5 25	3 00	2·06	1·56	1·88
Magnesia (MgO)	0 83	0·44	0·40	0·69	0·33
Lime (CaO)	0·54	0·32	0·30	0·30	0·40
Potash (K_2O)	1·48	1·42	1·31	1·45	1·20
Soda (Na_2O)	0 27	0·36	0·49	0·48	0·24
Loss on ignition	11·04	8·72	10 78	14·34	15·74

CALCULATED RATIONAL ANALYSES.

Felspar	59·5	51·0	64·4	70·5	66·2
Clay	10 5	10·7	10·8	11·6	8·6
Quartz	20·9	32·5	20·7	11·2	16·6
Lime	5·25	3·0	2·06	1·56	1·88
Iron Oxide	0·54	0 32	0·30	0·3	0·40

TABLE V—SIEVE ANALYSES OF RAW CLAYS.

	O	D	V	S	Z
Stays on 20's	22·7	67·1	35·0	62·8	65 0
,, 80's	44·5	23·5	40·2	31·4	23·2
,, 120's	17·2	8·8	21·0	2 6	10·0
Through 120's	15·7	0.5	4·2	3·1	0·7
Surface factor	1139	388	780	414	412

TABLE VI—MIXING CHART WITH EASY AND HARD-FIRED GROG

Lab. Mark	A B Series Grog Fired to Cone 10		Lab. Mark	E M Series Grog Fired to Cone 1	
	Clay	Grog		Clay	Grog
A1	1	1 fine	E2	1	1 medium
A2	1	1 medium	E4	2	1 fine
A3	1	1 coarse	E5	2	1 medium
B1	3	2 fine	M1	—	—
B2	3	2 medium	M2	1	1 medium
B3	3	2 coarse	M4	2	1 fine
A4	2	1 fine	M5	2	1 medium
A5	2	1 medium	M6	2	1 coarse
A6	2	1 coarse			

All M machine made.

TABLE VII—REFRACTORY UNDER LOAD OF EXPERIMENTAL BRICKS (50 LBS. PER SQUARE INCH).

Mark	Mixture	V	Z	O	D	S
		Cones	Cones	Cones	Cones	Cones
A1	1 clay 1 fine grog	14-15	10-11	13-14	8	14
A2	1 clay 1 medium grog	16	13-14	13-14	9-10	11-12
A3	1 clay 1 coarse grog	14	8	13-14	10-11	11-12
B1	3 clay 2 fine grog	16	12	14-15	11	13-14
B2	3 clay 2 medium grog	15-16	10	14-15	10	13-14
B3	3 clay 2 coarse grog	16	10	13	11	14
A4	2 clay 1 fine grog	17-18	9	13	13-14	14
A5	2 clay 1 medium grog	14-15	8	13-14	13-14	12-13
A6	2 clay 1 coarse grog	15	9	13	13	13-14

All the V series deformed very steadily.

The Z series collapsed very quickly once they had started, especially A3, B3, and A6; the failure being usually diagonally.

The O series deformed steadily, and all were more or less vitrified.

The D series collapsed suddenly once they had started, especially A5, B3, and A6. They usually cracked diagonally.

All the S series deformed fairly regularly and uniformly. A3, B3, and A6 broke diagonally.

TABLE VIII—REFRACTORINESS OF EXPERIMENTAL BRICKS UNDER NO LOAD

(Extremes of the sets indicated in Table VII).

Brick	Softening Cone	Brick	Softening Cone
VA3	31-32	OA3	20
VA4	30-31	OA4	20-26
		DA3	26-27
		DA4	20-26
ZA3	31	SA3	31
ZA4	31	SA4	31

The conclusions from the set of tests indicated in Table VII are as follows:—

Size of grog constant, proportion variable.—The less the proportion of fine grog to clay, the higher the refractoriness under load with V and D series. With the O and S series there is no appreciable difference. The breakdown with Z series points to the possibility of a maximum effect being obtained with a particular proportion of fine grog and clay, and,

taken in conjunction with the other series, this maximum will vary with each clay. Similar remarks apply with the medium and coarse sizes of grog, but the effects are less marked.

Proportion of grog constant, size variable.—In fifteen sets of experiments increasing the size of grog had no specially marked effect on seven of the sets, it decreased the refractoriness of five of the sets, it increased the refractoriness in one set, and showed a maximum in two of the sets. These three anomalous results want investigating further, to find if they are due to any peculiarity in the clay, or to errors in work. It will be observed that the grain of the clay, the possible and actual deflocculation, is an uncertain factor. This point will be taken up again in a subsequent report.

In order to find if the firing temperature of the bricks has any influence on the refractoriness under load, some bricks were refired to cones 15–16 for two hours, and the bricks became much more resistant. For example, the ZA4 series collapsed at cone 9 under a load of 50 lbs. per square inch with bricks burned at cone 10, and the bricks collapsed at cones 14–15 when they had been burned at cones 15–16. This makes it probable that the flux, or whatever it is which binds the constituent parts of the firebrick together, during the burning, is less viscous with firebricks burned to cone 10 than with firebricks burned to cone 16. It is probable that the fluxes during the burning of the brick are dissolving the less fusible constituents, and thus becoming more and more viscous. With firebricks burned at cone 10 these fluxes are still capable of dissolving more of the less fusible constituents, so that by thoroughly burning the bricks at a high temperature the binding flux is stiffened, and the resulting firebrick is more resistant to refractoriness under load.

XXXV.—Science and the Practical Man.

By Cosmo Johns, F.G.S., M.I.Mech.E.

NEVER before have the great Departments of State been so awake to the importance of scientific principles, or the people so intensely occupied in their application for purposes of construction and destruction. The leading technical societies have never been so flourishing if measured by the increased membership and the volume of the papers submitted. But most remarkable of all is the fact that the man who prides himself on being practical has become converted to the value of science, and does not hesitate to express the opinion that science and industry must enter into and maintain closer relationship. The newly converted are, however, not always the best informed as to the nature of the cult which has secured their approval and enthusiastic support, and it is because of this new-born enthusiasm of the practical man for science and its methods that it may be useful and perhaps necessary to explain briefly what science really is and thus to learn its real relationship to industry.

Now the ability to use instruments of precision and make physical measurements or to undertake routine chemical measurements does not constitute a scientist. Any intelligent young man or woman can be taught to use pyrometers, gauges, micrometers, or to make routine analyses, in a very short time, and the standard of intelligence required is by no means high. They can obtain results that are sufficiently accurate for most industrial work, but they are not physicists or chemists, and would have no knowledge of the scientific principles involved. Still less would they be able to interpret the results they obtained. They have merely obtained numerical values of volume, mass or temperature, by routine methods, which are necessary for the progress of certain industrial operations. The adoption of such methods involving the use of carefully determined data indicates marked progress in that particular industry and constitutes an important application of science; but it is not science itself, nor are the operators scientists. Inability to distinguish between the principles of science and industrial applications of science is responsible for much of the misunderstanding that exists, and might help to explain why science is not held in the repute it deserves in some quarters.

Science is but the search for truth; it is not utilitarian, and is pursued, not for any direct benefit it might promise, but because its votaries seek to comprehend the principles which govern the material universe and to discover the laws which operate. The impelling motive is the love of knowledge, the joy of discovery, and the only reward the approval of the few who are competent to judge. The discoveries made as a result of careful enquiry and the patient accumulation of facts eventually become enunciated as laws, rules, or principles. It is the knowledge of these laws, rules, or principles, and the ability to interpret new data or later observations in terms of these laws that constitutes the scientific mind. These discoveries —none of them of any utilitarian value when first announced— are the only real knowledge we possess. They are the milestones which mark the road along which civilized man has progressed. The utilization of these discoveries by their application to the service of man is technology. There is only one science and that is pure science. Those who speak of applied science only help to perpetuate confusion by the implication, if not the suggestion, that there are two sorts of science, namely, pure and applied. It is more correct to distinguish between the domain of pure science and the fertile field of the applications of scientific principles by calling the one science and the other technology.

As a people we are distinguished as being rich in original discoveries, but hardly successful in evolving the great industrial organizations that are now necessary for the successful application of scientific principles. There are striking exceptions, of course, in the industrial history of this country, but they do not disturb the rule mentioned. There is a marked contrast when we consider the Teutonic peoples, where, despite the advantages of a better educational system and greater facilities for the prosecution of scientific research, there is a comparative lack of those great creative minds whose efforts in the search for truth carry the boundaries of knowledge on in great marches, yet that same people, probably because of their educational facilities, have contrived to evolve vast industrial organizations where the application of scientific principles and extensive research based on those principles are marked characteristics.

We have now seen that the discovery of the scientific law was made with no idea of its utilization; it should be noted that rarely is it the case that the discovery does not find some application eventually. There is, however, a marked lag, as a rule, between the discovery and its application. The interval that elapses is sometimes due to the fact that those who might

have been able to apply the discovery have not been aware that the new knowledge was available; but more often the delay is due to the fact that there did not appear to be any application when the original contribution to scientific knowledge was made. There have, however, been cases when the new law or rule has been forgotten or overlooked and then brought to life later. It can be stated, almost with the certainty of a law, that the discovery in pure science long antedates its application in industry.

When Mendel, in 1866, published the results of his plant-breeding experiments, and arrived at the generalizations now known as Mendel's Laws, they failed to arrest the attention of biologists, and it was not until 1896 and the succeeding years that the almost forgotten papers were rescued from oblivion and their value recognised. To-day the fields of Eastern England are green with wheat sown with seed bred according to Mendel's Laws, and in India results even more startling have been obtained, and it is difficult to set limits to what may be considered possible in the direction of segregating desirable characters in the same organism.

When Haines first observed the selective action of oils on metallic sulphides there was but mild interest—and even that only academic—evinced. Carrie Everson had probably not heard of Haines' work when she commenced the experiments which finally led to her patent for concentrating the valuable sulphides in lean finely crushed ores by the now famous oil flotation process, which was granted in 1886. It was not until 1900 that the rapidly accumulating piles of lean ores attracted attention and industrial experiments on a big scale were undertaken, and processes, almost identical in their essential principles with that worked out by Carrie Everson, evolved which have revolutionised the metallurgy of the non-ferrous metals.

When Willard Gibbs formulated his now famous Phase Rule in 1876 its relation to industry seemed very remote. It was not until 1896 to 1900, when its applicability to the problems then pressing for solution in the realm of metallurgy was demonstrated by Roozeboom when interpreting the results of Roberts-Austen in the iron alloys, and by Heycock and Neville for the copper-tin system, that it became clear that a new and powerful weapon was ready to hand, and the brilliant advances in metallurgy of the last 20 years affords an eloquent example of the value to industry of a long overlooked contribution to pure knowledge.

Faraday in his researches during the early part of the 19th century formulated the laws of electrical science, and to-day the vast industries based on the production, transmission and

utilization of electrical power are a token that the discoveries of a philosopher may transfigure the surface of the earth and give to the activities of mankind a new orientation. When Clerk Maxwell published his electro-magnetic theory of light in 1873 its application to the services of mankind was a very remote possibility. The discoveries of Hertz in 1887 afforded a brilliant confirmation of Clerk Maxwell's theory, and Crooke's in 1900 could point out that the wireless transmission of messages was now a possibility. The achievements of the last few years are too well-known to require recital; to-day the ether is pulsating as messages are spreading across oceans and continents. In each example we can note the mild academic interest in the original discovery; the remoteness of its possibility of becoming of use to mankind; the arrival of the interpreter and then its application on an industrial scale. The existence of these gaps in time between the discovery and its application is characteristic of the relation that exists between science and industry.

There still remain discoveries for which no application have been found. They will find their place some day in the armoury of the practical man when their nature has been defined in terms that he can understand. The radio-active elements and the revelation as to the extent of the energy locked up in the atom, Moseley's discoveries as to the relation of the known elements, and the significance of the atomic numbers and the location of the place of the five missing elements are but examples of recent additions to our knowledge, where the application is not apparent now but will certainly come later.

It is not without significance that science is economical in her methods. Some of the greatest discoveries have been made with the simplest apparatus. When the famous Wollaston was asked by a visitor to permit him to see his laboratory he instructed his servant to bring it up and it came *on a tray*. Their application to industry may and generally do consume decades in time and vast capital. Research in pure science is, for a nation, the most profitable investment that it could undertake. In the instances cited the discoverers never obtained any reward for the services they rendered the generation that followed them. Altruism cannot be carried much further than this. No better definition of science has been given than that which describes it as "organized common sense." It is but reasoning from ascertained facts according to sound principles.

The practical man is rather difficult to define. The rather witty remark that he is "one who practised the errors of his predecessor" would win wide approval if the mis-directed

energy and wasted opportunities that characterize so many industrial efforts be considered. But the men who threw bridges across estuaries, pierced mountain barriers with their tunnels, girdled continents with railways and are prepared to make the atmosphere a highway for commerce, must have practised their art successfully and could not have been in ignorance of the principles of science. They must have been eminently practical men. There must be real kinship between the really creative minds that are ever extending the boundaries of pure knowledge and those truly practical men whose indomitable wills and ready invention have made the forces of nature the servants of mankind. They have this in common, which serves to distinguish them from the rest of men, they possess the gift of intuition, which is only another name for generalized experience, to lead them in the right direction where others in the face of conflicting and apparently unrelated facts would lose heart and confess defeat. Both stand on the frontiers of human experience, their task to blaze new trails and extend man's dominion over the world he inhabits.

The great creative minds are not many in number, and the real pioneers are but few. Industrial progress demands leaders and interpreters, who from their knowledge of the teaching of science can apply scientific principles as a key to the solution of industrial problems. Imbued with the spirit of science they should be in touch with the needs of industry. Conversant with the laws of science they should be adept in their application. It is to state a truism that only those who know science can be entrusted with its application, yet that simple truth has not yet reached all who are responsible for the direction and control of industrial undertakings. In order that the findings of science might be fruitful in application to industry it is necessary that those responsible for such applications should have a sound training in pure science and an introduction to the technology of the industry they mean to enter. In the presence of members from so many industrial areas, many of which possess excellent institutions for higher training in science and technology, it may help to avoid controversy and possible bias if the metallurgical course at the Imperial College of Science and Technology be indicated as the type of training required for those whose aim is to direct the application of scientific principles to the solution of the problems of the metallurgical and related industries. The insistence on a good standard of knowledge on entrance; the two years devoted to the study of pure science followed by two years technological training represents the minimum time and standard that should satisfy those responsible for the

government and support of a centre of higher training in science and technology.

But the interpreter of science to industry has not been completely defined until his function has been recognised and it has been decided whether his field is that of research or that of directing and controlling industrial operations. Both types of men are required in industry, but they are two different types, and their training should vary as their functions. The one deals with the problems of industry in the chemical or physical laboratory; his distinguishing characteristic should be ability to undertake scientific research, which seems to mark him off from the routine analyst or laboratory assistant, who lacks the sound training in scientific principles of the trained research worker. The other type functions as an engineer, he has to direct and control the actual industrial processes. He may be a mechanical engineer, a metallurgical engineer, a chemical engineer, according to the class of industry in which he is engaged. The idea that the engineer is one who has to do with steam-engines still lingers among the uninstructed. The engineer can be defined as one who "directs energy changes to the service of mankind." He directs manual labour; the plant which he controls is made of the common materials of construction. His operations are on an industrial scale, and commercial success is the measure of his efficiency. The same man might be equally successful as the research worker and as the engineer; but the capacity of human mind is limited, and the two types indicated require to be differentiated in the later stages of their training and their functions in industry defined. Both types are needed, but industry is not always aware of it.

The necessity for research on an extensive scale is nowhere more apparent than in the refractories industry. The problems involved are so complex, and the hiatus in our knowledge so great that it has been estimated that if every laboratory in the country qualified for, or that has promised to, undertake research work in refractories could start at once on its task it would require at least ten years' work before any real progress could be reported. There is overwhelming evidence that isolated efforts will not suffice for the solution of the many problems that await attack, and that nothing less than associated work on a national scale on the broad lines suggested for the proposed National Association for Refractories Research will meet the case. The national riches of this favoured land of ours are not only hardly exploited, they are but imperfectly known. Richly endowed with coalfields favourably situated for commerce, with iron ores accessible and extensive, with the

raw materials for refractories and limestone and salt conveniently at hand, the wonder is not that we are a great industrial nation but that our natural riches have not been more completely surveyed, our great advantages better employed, and that the land which holds such a high place as the home of the greatest creative minds in the domain of pure science should have permitted itself to be outstripped in the application of scientific principles to industrial undertakings. That our people do not lack capacity is clearly evidenced by the miracles of industrial achievement that four years of war have produced.

In the days of peace that will come, for war is but a more active period in the industrial competition of nations, the great task awaits the nations of achieving the replenishment of an impoverished earth. That people will achieve success in the commercial struggle that is to follow who can most firmly establish the effective relationship between science and the practical man.

XXXVI.—Notes on the "Sang de Bœuf" and the Copper-Red Chinese Glazes.

By J. N. Collie, L.L.D., D.Sc., F.R.S.

TWO years ago the author, in some "Notes on some Chinese Glazes on Pottery and Porcelain," pointed out that the older glazes of the Ming and earlier dynasties contained notable amounts of phosphates, but that in the later glazes of the Ch'ing Dynasty phosphates were almost entirely absent. Also that the green copper lead glaze that has played such an important part in the decoration of the finest Chinese porcelain was the same glaze that had been used by the Chinese in the early Tang and Han times, and could be traced back to the XIth Egyptian Dynasty 3,000—4,000 B.C.

Since then the author has been able to investigate another copper glaze, viz.: the red copper or reduced copper glaze. In the green copper glaze the copper is present in the form of a cupric or fully oxidized copper compound, in the red glaze the copper is present in the reduced state, either as a cuprous salt or as metallic copper in the colloidal state diffused through the glaze. At present it is impossible to say with certainty whether this magnificent red colour is due to a cuprous silicate or to colloidal copper. Yet if one compares it with the beautiful famille rose colour, which is almost certainly due to colloidal gold, the copper red must be the result of infinitely fine particles of metallic copper in the colloidal state diffused through the glaze. This theory receives a certain amount of support from the fact that the slightest overheating of the red glaze in the furnace destroys the colour, first rendering it dull brown or opaque, and then finally the colour almost entirely disappears.

There is no reason to suppose that a cuprous silicate would be so susceptible to small changes of temperature, but we do know that colloidal solutions of metals easily undergo change in their molecular aggregation, and thereby also change in colour with small changes of temperature. This would account for the dull brown of the overheated copper glaze, for by heating the colloidal state is broken down, the particles of the copper begin to come together, rendering the glaze opaque; finally, by more violent heating, they fuse together into infinitesimal

globules of metallic copper too small to be seen by the eye and so the glaze would appear colourless. The history of this red copper glaze on Chinese porcelain is one that is of some interest, for it was one of the oldest of their felspathic glazes. Moreover, the secret for its production was lost for a while and then rediscovered. Also all attempts to produce this brilliant red glaze by European potters were unsuccessful until about thirty years ago.

The first mention of this glaze is in the reign of Hsüan-Té (1426—1435). In an old manuscript of the 16th century by Hsiang Yuan-Pien eleven different specimens are mentioned, and coloured drawings show the appearance of it. It was, however, only produced in small quantities and was called "Chi-hung" ware or "sacrificial red." Hsiang Yuan-Pien is most enthusiastic in his description of the various pieces. He says: "Among the ceramic productions of the reign of Hsüan-Té, deep red is the one variety that is most valued of all. Probably this is because, in the preparation of the colour, red precious stones from the west were pulverized for the glazes, so that, after the porcelain had been fired, flashes of ruby-red sheen shone out from the depths of the rich glaze, dazzling the eyes." And again, "It is truly the very crown of our collections of celebrated porcelain of different dynasties," and "The tint of the red is crimson like fresh blood," or "of the tone of ripe red cherries, or, rather, like the precious stones brought by the turbaned red-socked nomads" from the west. Unfortunately none of these beautiful specimens of the sacrificial red have survived, and the art for the production of this underglaze red failed very soon after the reign of Hsüan-Té, for we find that during the reign of Chia-ching (1522—1566) the imperial potters could no longer produce this glaze, and petitioned to be allowed to decorate the porcelain with an overglaze iron red instead.

Whether this was due to the original supply of the copper mineral having come to an end, or from some other cause, we do not know. Although we have no specimens of this Hsüan-Té red, yet there is little doubt but that it was a copper red underneath a felspathic glaze and produced at a high temperature.

Although none of the sacrificial red has survived, yet there are certain pieces of old Corean ware that can be put in the same class with it. These pieces are covered with a very pale translucent green glaze, and underneath the glaze are leaves and patterns in pinkish red with flashes here and there of "crimson like fresh blood." This colour contains copper, and, if instead of leaves there were fish, we could imagine that these pieces might be "Chi-hung" ware of the Hsüan-Té period.

Unfortunately the date of this Corean ware is unknown, but although it is old, it is certainly later than the Korai period which was contemporaneous with the Sung. It might, however, be of the same age as the Hsüan-Té sacrificial red.

In the year 1644 the Ming Dynasty came to an end and was succeeded by the Manchu or Ch'ing Dynasty. But it was not till the reign of K'ang Hsi (1662—1722) that the manufacture of porcelain on a large scale was again started. One of the earliest glazes was the Lang Yao copper red or "sang de bœuf." This beautiful glaze was presumably the same as the "sacrificial red" of the Hsüan-Té period, and is the "Chi-hung" of the K'ang Hsi time. It is described in the letters of Père d'Entrecolles in 1712 and 1722. According to R. L. Hobson[1] "the secret of the glaze, which Père d'Entrecolles tells us was carefully guarded, seems to have been lost altogether about the end of the K'ang Hsi period." Whether this was so or not we find that the later specimens of sang de bœuf lost the brilliancy of the Lang Yao red, becoming streaked with other colours, greys and purples being especially common in the sang de bœuf of the Ch'ien Lung and later times.

There seems to be great diversity of opinion about the age to be assigned to various specimens of the sang de bœuf of the Ch'ing period. For instance, it is said that the true Lang Yao must be a brilliant red, varying in depth and even entirely lost in places; there must be no purple or grey streaks, a faint crackle must be seen in the glaze, and the glaze must not run down on to the base but stop at the foot rim. The glaze under the base may be green or buff crackle or even plain white. Yet there are pieces of sang de bœuf that possess all the above characteristics, with the exception that the glaze has partly run down below the foot rim, which many connoisseurs will not allow to be K'ang Hsi porcelain. That the glaze never ran down in the early K'ang Hsi sang de bœuf is extremely improbable; with an extra thick glaze and a slightly higher temperature than usual it would be impossible to prevent it. Perhaps when it did occur the glaze might have been ground away from the base, and the piece was then refired to a temperature just sufficient to soften the glaze when all traces of grinding would be obliterated. As it would be more dangerous to refire big vases than small ones, it is to be expected that we should find the perfect rim of glaze more often on the small than on the large pieces.

Another puzzling peculiarity of the various specimens of sang de bœuf is the base. One ought to be able to decide something about the date and place of manufacture from the

[1] R. L. Hobson, Chinese Pottery and Porcelain, Vol. II, p. 124.

extremely diverse bases that occur on the various specimens of sang de bœuf. Some are green or buff colour, some plain white or straw yellow, others are without glaze, and are of a white or iron-rust colour, some are crackled, and some have a little of the sang de bœuf in the glaze. The glazes inside the vases also vary considerably, white, green, blue-green, and straw yellow, whilst sometimes they are crackled and sometimes plain.

The history of the sang de bœuf glaze has yet to be written. All we know about it is that after it had been rediscovered early in the reign of K'ang Hsi it was gradually perfected, and then as time went on less care was given to its production. From the large variety of bases the sang de bœuf must have been made in probably more than one factory and continuously up to the present times. The defects of the later specimens may be due to the particular supply of copper failing and a less pure material being used, thus giving greys and purples. The purple and grey colour of the later sang de bœuf perhaps may be due to phosphates. An early specimen of this glaze of a pure brilliant red contained no phosphate, whilst another piece with purple and grey splashes gave tests showing the presence of a notable amount of phosphate. Also the potters may have found that it was more easy to work with a glaze of lower melting point and more fluescent, which would account for some of the differences between the early and the later sang de bœuf.

Beautiful as the Lang Yao red is, yet in its technique it is by no means perfect; much more finished and more beautiful glazes were produced later. This is what is to be expected, for the Lang Yao was the first attempt to reproduce the sacrificial red. Although the red in the Lang Yao is very fine it is not so brilliant as the pigeon's blood or some of the later sang de bœuf. Moreover, the glaze of the Lang Yao is full of bubbles and pinholes, and has blackish streaks, especially near the base. By the end of the K'ang Hsi period a much more perfect glaze was made, and the finest specimens of this magnificent glaze were undoubtedly produced either then or at a slightly later date.

The amount of copper in the sang de bœuf glaze is very small, and if the glaze is fused in an oxidizing flame it becomes very pale blue-green in colour, and full of bubbles, the amount of copper being only just sufficient to impart a faint colour to the glaze. If a section running through the paste and the glaze be examined under the microscope, only a thin line of copper red is seen, it does not permeate more than a fraction of the glaze. How this layer of colloidal copper is produced in the glaze is not easily explained. But just as tin is necessary

to bring out the beautiful rose red of the colloidal gold in the famille rose so possibly it is the presence of another metal with the copper that conditions the formation of the magnificent sang de bœuf. There is no doubt that iron is present in the sang de bœuf glaze, and it is quite possible for a ferrous salt to reduce the copper in the glaze to the colloidal state. Moreover, Hsiang Yuan-Pien specially mentions that in the manufacture of the Chi-hung ware of the Hsüan-Té period "red precious stones from the west" were used. These probably were cornelians or red agates, and they owe their colour to oxide of iron. Also Père d'Entrecolles states that "when they intend to apply this red to porcelain they do not use porcelain stone (petuntse) in the body, but they use in its place, mixed with the porcelain earth (kaolin) a yellow clay prepared in the same way as petuntse." The yellow clay also owes its colour to oxide of iron. The qualitative analysis of several specimens of sang de bœuf glaze always showed appreciable amounts of oxide of iron, in fact apparently there was more iron than copper, the latter being present only in small amount, probably much less than 1 per cent. Phosphates seemed to be absent, and the glaze, as far as could be seen from the analysis, was the ordinary felspathic glaze containing silica, alumina, lime and alkalies.

But this red felspathic copper glaze is not the only copper red that has been used by the Chinese. There is another glaze that is not so often seen, but one that is as brilliant a red as the best sang be bœuf, with this difference, however, it is opaque. This glaze is not a felspathic glaze but a lead glaze, and apparently is far older than the sang de bœuf. The earliest example that the author has come across is in Roman Egyptian glass. This glass, when polished, has the colour of the finest and most brilliant sang de bœuf; it is quite opaque, and when broken is vitreous and like the best red sealing wax. The author is indebted to Sir Herbert Jackson for the following partial analysis:—

ROMAN EGYPTIAN GLASS.

Silica	SiO_2 ...	= 38·20	per cent.
Lead oxide	PbO ...	= 31·10	,,
Copper, as	CuO ...	= 4·67	,,
Alumina and iron oxide ...	Al_2O_3 and F_2O_3	= 2·10	,,
Manganese oxide... ...	MnO ...	= 0·10	,,
Lime	CaO ...	= 8·15	,,
Potash	K_2O ...	= 0·61	,,
Soda	Na_2O ...	= 10·29	,,
Tin oxide	SnO_2 ...	= 0·70	,,

The author also determined the lead and copper, finding $PbO = 32·6$ per cent. and $CuO = 5·4$ per cent. This glaze,

therefore, is similar to the green copper lead glaze, with this difference, however, its copper is in the reduced condition.

The earliest Chinese example of this red glaze that the author has been able to examine is a vase that is certainly early Ming, and from its appearance and the splash of coloured glaze on the base might even be of Yuan date. In colour it is more red than iron rust; it might be called a brownish sang de bœuf. The colour is chiefly due to iron, but there is an appreciable amount of copper present as well. The glaze is a lead glaze and very easily fusible. That a possible dark red copper lead silicate was used in Ming times is proved by a brilliant dark red enamel from an old piece of Ming cloisonné being found to contain copper and iron, whilst in the lighter coloured brick red enamel of some Ch'ien Lung cloisonné no copper could be detected. Another specimen of this glaze was analysed. It came from a Chinese porcelain figure of a dog. This glaze is of the same colour as the Roman Egyptian glass, a brilliant sang de bœuf red, and like the glass it is quite opaque. It has a mottled appearance, also it is a lead copper glaze. It is undoubtedly old, possibly of Ming date, but perhaps it may be late 17th century ware. Enough of this glaze could be chipped from the base to enable a rough quantitative analysis to be made, with the following results:—

Lead oxide ...	28	per cent.
Copper, as [?]	2	,,
Iron oxide ...	2	,,
Phosphoric oxide,	trace	

From these figures it will be seen that it does not differ much from the Roman Egyptian glass, and although it is most probable that the Chinese discovered this glaze for themselves. yet it is of interest that 1,500 years earlier the same sort of material was known to the Egyptians, just as the green copper lead glaze was also known to the people on the banks of the Nile centuries before the Chinese made use of it.

It is remarkable, however, that this intensely brilliant lead-copper glaze should not have been used to a greater extent by the Chinese. There seem to be very few specimens of it. Perhaps it was difficult to work, perhaps also it may be that, as it is probably a southern Chinese or Canton glaze, it was unknown to the potters elsewhere in China.

XXXVII.—The Essential Properties of Refractories used in Steel Production.

By Alleyne Reynolds.

THE history of how this paper came to be written being germane to its very nature and objects its author thinks it is desirable to set this out. Up to some twenty years ago he was employed by the well-known Vickers firm as manager of their acid open hearth, crucible steel melting and kindred plants, and also of their gun and armour plate heat treatment plants. He had to produce steel ingots and castings, some of which had created, for the time being, world records in regard to dimensions and weight. He had to produce steels, with most regular success, fulfilling very narrow and severe specifications, and of great variety in regard to composition, and also in regard to weight of the individual ingots and castings.

In 1896, as a result of his observations of subtle phenomena in the various processes, which subtle phenomena in one process, tended to cause him to perceive analogous phenomena in other processes, and to endeavour to correlate them, led to his concluding that conventional theories and explanations given in the literature were not merely inadequate, but often inaccurate, and even quite opposite to the truth. For example, he came to recognise that far from the acid open hearth being the simplest steel process, its metallurgy was much the most complicated of any of the known steel producing processes. Further, and in particular, he recognised that the small margin of higher resistance to fusion possessed by available refractories over that of pure iron was so small as to render it impossible to actually and truly dead melt (*i.e.*, retain molten in the absence of exothermic chemical change) steel in open hearth furnaces, particularly acid ones.

It became clearly apparent to him that acid hearths were continuously oxidizing to molten steel, that such action was endothermic, and also that acid slags were continuously oxidizing to the steel, and ordinary basic ones still more so. Further, that the very serious metallurgical defects in question alone compensated for the deficiencies of the furnaces, and rendered it possible to produce steels of reasonable commercial,

but never perfect, quality by the open hearth processes. Although it is *prima facie* utterly absurd to smelt the reduced product of basic ores in an acid furnace, yet the balance of the compromises between the various fundamentally bad conditions was overwhelmingly in favour of the acid process.

Being driven to find explanations himself to fit observed facts he necessarily became considerably non-orthodox in many of his ideas.

Towards the end of 1897 he resigned his appointment with the Vickers firm and has since devoted the bulk of his time and private means to a "lone hand" crusade with a view to the evolution of furnaces and processes by means of which truly dead melted steel of any composition compatible with Nature's dictates may be made of uniform composition, and with certainty and ease, in ingots or castings of any weight, and not require the great skill and costly manufacture inherent to the acid process, by means of which latter it is possible to make good, but absolutely impossible to make perfect, steels.

One step in the problem of producing perfect steel being to evolve improved open hearth furnaces within the limits of present day refractories' properties, the author considered this, and as a result read in May, 1913, a paper entitled "Faults in present day Furnaces, and their Remedies," at the meeting of the Iron & Steel Institute. Another step was to endeavour to inspire manufacturers of refractories to produce better and more suitable materials for furnace construction and endeavour to make them understand what properties were required.

When a native oxide ore is sought to be reduced to the metal it can only be rendered quite free from oxygen by means of reducing agents so powerful that the reaction is an irreversible one, save where the oxide of the reducing agent is gaseous and thus is divorced from the chemical system. In any other event the native oxide can only be partially reduced. The metallic product can only be free from contamination by oxides of itself, or of the reducing agents employed, subject to the proviso that such oxides are insoluble and non-emulsifiable therein.

It is extremely difficult to make iron or steel free from oxides. The metal iron possessing a fusion point of some 1,500° C., and being a very powerful reducing agent when molten, acts reversibly with all reducing agents save Al, Ca, and Mg amongst the elements. Further, it is a most powerful solvent of its own protoxide, the more so the more it is superheated.

The three non-reciprocally acting elements named are inapplicable as reducing agents, as the oxide produced is refractory

and is emulsified. There is only one substance, silico-manganese, fulfilling the requirements of an eliminator of all oxygen from molten iron, viz.: that the product of its oxidation is insoluble in, and sufficiently fusible not to be emulsified in it, and, further, to be irreducible thereby. This the author hopes to prove. Further, as will be shown, even the oxides of Al, Ca, and Mg are almost certainly oxidizing to iron if contaminated by free alkali. Even if pure, all acid refractories are, so he contends, oxidizing agents for molten iron, and this contention he bases on theoretical grounds, owing their origin, as before stated, to his practical observations, and confirmed as a result of trials deliberately made to test the issue.

The results of these trials, together with notes bearing on the subject, are given in the appendices, and readers may draw their own conclusions therefrom.

The diseases of steel which are not clearly understood are almost wholly traceable to oxides and nitrides.

Nitrogen compounds are almost all endothermally formed at high temperatures, and, for this reason, the author has always looked askance at the only practicable form of electric steel-smelting furnace, the semi-arc type. This depends on locally creating very excessive temperature, which in turn involves grave risk of introducing nitrogen into the steel.

In the absence of some exposition of the at present unknown, primary laws of thermal chemical reaction, viz.: those governing the inception temperature thereof, one cannot hope to realise the governing influences, or adequately understand what steps of action have occurred, from a study of the results of trials such as those given in the appendices. These trials were made for the most part to test theories built up by synthetical reasoning, and to endeavour to render possible the identification of actions occurring, well knowing that this course of procedure would not be likely to produce useable products; the object being to diagnose the causes of the diseases of steel with a view to the evolution of processes for the production of better steels.

Much more copious and costly trials on these lines are required, and such are only to be adequately made with the full-sized units of plant in actual commercially producing steel-works.

The national importance of the industry, and the importance of freedom from defect of railway axles and tyres, guns, and other structures, are of a nature so directly concerning the public weal, that a large Government grant for this express purpose would be much in the public interest.

Tests taken in the course of ordinary trade routine manufacture furnish very little knowledge of the all-important steps by which chemical reactions in such a high temperature metallurgical process occur.

The arguments which follow are based on novel theories of the author's, and he trusts that his readers will be patient in regard to his "begging the question," until they have seen how remarkably they account for and are borne out by facts of a most diverse nature.

Space does not admit of his attempting to elaborate or adequately justify them, nor has he fully worked them out and tested them himself. They are based on absolutely abstract thought. The heat change accompanying a given chemical reaction is independent of the actual or conceivable steps by which it occurs.

Measurements of the heat evolved or absorbed during the occurrence of a reaction in the calorimeter are affected by heat being rendered latent or active owing to the difference between the specific heat of the reagent and that of the products of reaction. This amount is a function of the temperature at which the reaction actually takes place. At any rate, at the time, this is an unknown quantity.

With an efficient calorimeter the temperature of the reagents and products of reaction, during its progress from ignition, is maintained little in excess of that of ignition, thus the calorimeter reading is in error to the extent of the difference t_c to t_r C. between the heat contents of the reagents and products of reaction, where t_c = the mean temperature of the calorimeter and t_r = the temperature of incipient reaction plus about one-half the rise of temperature of the calorimeter.

It seems reasonable to assume tentatively that chemical reaction is incepted, and can occur to the extent that starting from the temperature of its inception, its occurrence to the limit it can take place and complete reciprocation would restore the status quo; the evolution or absorption of active heat depending on the extent to which the reaction is able to take place, which, in turn, is dependent on the products of reaction, and unacted-on reagents and inert matter, being in equilibrium of temperature when the reaction has proceeded to the limit possible.

It seems reasonable to assume that at a given temperature $T°$ absolute, a given weight of a given substance possesses a fixed total heat content, or sum of latent and sensible heat, and that this is independent of the steps accompanying its composition from the elements.

Following up this train of thought the author has come to the conclusion that the following is some expression for the formula for arriving at the inception temperature of an endothermic reaction:—

The inception temperature of an endothermic chemical reaction is that temperature v° C. at which the heat content O° to t° C. of the reagents equals the calorimetric value of the heat which will be absorbed by the reaction, provided that the phases of the reagents and of the products of reaction are alike at the temperature of reaction, and also alike at the normal temperature of the calorimeter.

The temperature of inception of an endothermic reaction must be that of non-association of its reciprocal.

The phenomenon of catalysis remains to be fully explained. The words catalyte and catalyst seem to be rather indiscriminately used, but the author begs to suggest that they should not be used loosely, and to define them for the purposes of the present paper.

There are two distinct types of catalytic action characterized by the fact that an intermediate substance is acted on simultaneously in exactly opposite directions by reagents, the reaction of which it bridges, with the result that its composition remains constant.

In the one type the intermediary waxes or wanes in amount with varying temperature, or at constant temperature during progress of the reaction, of the occurrence of which it is the causation. Again, its mass action is concerned.

In the other type the mass action of the unchanged intermediary is not a function of the reaction, and its mass remains unchanged. Further, its mass may be so minute that its presence may easily be overlooked.

Intermediaries of the former type will be termed *catalytes*, whilst those of the latter type will be termed *catalysts*.

Disregarding coefficients of the catalytically acting substances, we calculate that a very high ignition temperature is required for a reaction of the type $Y+ZO=YO+Z$; at a much lower temperature either of the two following reactions may occur $X+ZO=XO+Z$, or $Y+XO=YO+X$. It follows, therefore, that both will occur, and X remain unchanged. X is therefore a catalyte or catalyst, according to whether its mass action is essential or otherwise.

All problems facing ceramists and steel makers now admit of direct attack, and a sketch of the requirements of philosophic steel making will serve as a guide to any other metallurgical process.

In smelting iron ores the primary object is to produce pure iron, either as such, or as a basis for alloys. Carbon being the

most universal solid fuel, the products of the operation should be pure iron and CO_2, in so far as the laws of nature permit. Instead of trying false ideal methods we should follow the line of least resistance. We should seek the aid of catalytes and catalysts, and in all possible ways conduct the smelting process at the *lowest possible mean temperature.* We should aim at increasing the heat content of the reagents with a minimum increase of their temperature.

We must as a first step then provide for a flux. We must hold or remove the objectionable acids. We should commence by replacing the more objectionable acid, by means of less objectionable acid, by additions of such to the ore. We should also add bases so as to render the mixture basic in respect of the FeO (when combined). The most powerful bases associate themselves with the weakest acids. Usually we find then that in adding a more powerful base we have to do so as a carbonate. Usually we find iron oxides associated with three acids, carbonic, phosphoric, silicic, and the very powerful base lime, mainly as carbonate. We should therefore commence by adding silicate of iron to the mixture, so as to get rid of some of the carbonic acid, and also provide a flux.

To conduct a caloric process in one operation involves all the re-agents, products, and bye-products, being kept in equilibrium of temperature, *which temperature is that of the maximum required for the highest step—therefore the steps of removing each acid and base should be separate metallurgical processes, conducted in separate furnaces, suited for one and unsuitable for another step.*

It is an apt illustration of necessity being the mother of either invention or adoption, that the great Austrian firm of Witkowitz, owing to being faced with worse ores than any other great firm, have been nearly always ahead of the world in their methods of producing cheap steel. They were the first firm (to the author's knowledge) to charge open hearth furnace slag into their blast furnaces, and to desiliconise steel by a totally separate process from dephosphorising it, and to use lime, instead of carbonate of lime, in the dephosphorising process. The last process of a series should be exothermic, and the highest temperature process. The author's inventions are based on this. Witkowitz, in common with all other steel making firms, have been illogical in attempting to combine the two last stages in one process, viz.: the refining and finishing processes.

They were, however, the only firm with the plant and willingness to try the author's final step process on the grand scale, and arrangements were complete for the author to make trials there on the 70-ton scale when this war broke out, and

resulted in the disappointment of his years of work and expenditure being rendered abortive.

The manufacture of steel then must consist of one less stage than there are a total of acids and bases in the ore mixture, including fluxes. The first step must be in the regenerative blast furnace, or its equivalent the non-regenerative electric semi-arc vertical shaft furnace, in which the charge column above the reaction zone forms the most perfect regenerator that can be designed.

CO_2 is commonly the most easily reduced oxide present save H_2O, and therefore it is easy to understand why lumps of carbon and lumps of ore can interreact in a shaft furnace in the absence of being in contact at all.

Dealing first with the reduction of RO by C, assuming both to be pure. The interstices between the lumps are filled with air. This burns to CO_2, and this to CO. This CO acts as a cumulative catalyte. It reacts with RO and C simultaneously. It reacts with R and C also as a catalyte, producing carbide. The RC formed again acts as a cumulative catalyte causing penetration of reaction through the lumps of RO for the CO and CO_2 generated within the lumps burst the skin of equilibrium product, unless it be removed by fusion; thus, either sponginess or fusion causes penetration of reaction. Now nothing can control the product, for the furnace must automatically arrange its contents into zones, the bottom zone being one of superheating a product, and bye-product, in equilibrium with solid carbon. The reaction catalytic zone is above this, and the carbon electrode being merely a large lump of carbon takes part in maintaining the catalyte CO and is therefore eaten away at this zone into the form of an hour-glass. Above this zone is the lower temperature reduction of RO_x to RO zone if RO_x be the ore instead of RO. Above this the charge is a splendid regenerator.

Turning to actual ores, the zones are modified. In bad practice, in very usual practice, the blast furnace is used as a kiln to drive off carbonic acid, only burning carbon to CO in doing so. The carbonates, whether of lime or iron, should be roasted in a kiln and converted into oxides. Now silicate of iron from the steel furnaces is a good low grade ore usually wasted, and within proper reason should be used in the blast furnace instead of burning carbon in a kiln or the blast furnace to lessen the number of acids. As we have to employ an acid lined blast furnace we cannot produce as product other than a low silicide, full phosphide, high carbide metallic alloy as the final product of the first logical operation.

The sole difference between the blast and electric furnaces is that owing to avoiding transmutation of energy we work more cheaply and more regeneratively with less radiation losses by employing the total fuel in the large blast furnace. The gases are alike in composition save and except for (the useful mass action of) the nitrogen of the air blast.

The next process should be to treat the shaft furnace product by the acid open hearth continuous process, using as much limestone as possible to remove the silicide of iron, but using no ore. Above the metal level, and just below the top of maximum slag level, neutral or inert furnace brickwork is needed, at the teeming side, as acid bricks would be fluxed by oxidation of iron into basic FeO. If large lumps of lime carbonate were used, and kept well in the centre of the bath, considerable amounts of iron carbide would be removed, without risk of fluxing the hearth.

The third process should be exothermic refinement to produce lime phosphate. Plenty of carbonate of lime, or lime and iron ore should be used, and the process should be the Talbot process, but producing more commercially valuable slags owing to the acid process preceding it having been on logical lines.

Now, apart from temperature of ignition questions, it follows that where reagents are solutes in a mutual solvent reaction of an exothermic nature can only continue when as one reagent becomes in more dilute solution the other is in more concentrated solution. The last reaction must leave at the end of refinement an excess of a reagent as a solute. It must not leave a product of refinement as a solute in any phase.

The manufacture of pure iron is impossible, and the manufacture of steel originated out of ignorant attempts to produce iron. It was then found that steels, or alloys of excess reagents (deoxidisers) possessed better physical properties than iron was likely to possess, could it be made by a caloric process. Where skill comes in, where the author's inventions are designed to render skill unnecessary, is in the last process of refining out the last traces of the refining agent. This is FeO.

It would be out of place to omit reference to the pneumatic steel processes, properly all to be accredited to Bessemer. It would be equally out of place to omit to give credit for the discovery of their nature to Dr.. J. E. Stead. In 1877, that gentleman read a paper showing their nature.

Briefly the pneumatic process consists in creating iron-ore like substances by combustion of iron. Pig-iron is composed of some 60 per cent. of iron as the solvent of some 40 per cent.

of solutes which are metalloid compounds of iron and manganese. The total iron is about 93 per cent.

On driving oxygen through molten pig-iron the oxygen mainly combines with the 93 per cent. iron. The difference then between the open hearth and the pneumatic processes is that in the former we obtain heat mainly by burning coal in the furnace (indirectly of course), and create that balance of ore required to furnish the balance of heat requisite to furnish intensity essential, but at first and in the main, reducing added ore. In the latter we use iron almost wholly as fuel in creating ore, and a small balance of other fuel in creating slags and gases of combustion of carbides.

It seems an illogical process, but owing to its exothermic nature it is not wholly so. Radiation losses are so severe over a protracted period in small open hearth furnaces as to render a more costly fuel justified if time enough be saved to compensate for this.

The Bessemer converter is Nature's text book. The best deoxidizing agent must be the substance which forms the first slag in the Bessemer converter, and the worst that which forms the last. The proper sequence of separate stages of steel refinement must be the sequence of reactions in the Bessemer converter.

The order of oxidation is at low temperature, silico-manganese, silico-iron, carbon, phosphorus. At high temperatures silico-iron is not only not attacked but formed. Then the sequence is silico-manganese, carbon, phosphorus. In the basic process where phosphatic slags exist in addition to silicate slags, the carbon reaction merely requires high temperature, and is independent of the phosphorus reaction, provided sufficient base be present.

Clearly then the fourth process which the author insists on must be a treatment by silico-manganese.

Further notes bearing on the subject will be found in Appendix XV.

Only extremely crude calculations are required to show what classes of reactions are likely or unlikely to occur.

For the purposes of acquiring some idea of the nature of the problems involved in steel manufacture a few calculations are appended based on the very roughly approximate assumptions that the heat content of all elements at high temperature is 7 calories per gramme-atom multiplied by the temperature, except in the case of carbon, where it was taken at 4·4 calories multiplied by the temperature. Further, the heat content of compounds is (inexactly) taken as the sum of the heat contents of the elements of which they are composed.

The reducing power of carbon on RO at 1,500° C. is arrived at as follows:—

Heat content of carbon 4·4 × 1,500 ...	= 6,600	cals.
„ „ „ RO 14·0 × 1,500 ...	= 21,000	„
Heat of combustion of CO	= 68,200	„
Total	95,800	„

If in lieu of RO the oxide be RO_2 one must subtract 3·5 × 1,500 or 5,250 cals. from the above, and if it be R_2O 7 × 1,500 or 10,500 cals. must be added thereto. This at once shows that at steel making temperatures of the higher order one may expect to reduce all oxides save silica, alumina, lime and magnesia by means of carbon. Further, that the reduction of the alkaline oxides yields metals which are, in turn, powerful reducing agents owing to only one atom of oxygen being combined with two of the metal. The alkalis and metals of the alkali group are therefore powerful catalytic agents. This property may cause them to bring about hundreds of unsuspected reactions, and their presence in refractories should be most studiously avoided where not deliberately sought. They may cause the most powerful bases to be liable to attack except when combined with acids.

Sulphide-Oxide Reaction. Smelting Temperatures.

$FeS + 2FeO = SO_2 + 3Fe$ (+69,300 − 24,000 − 131,400) = −86,100 cals. 86,100 ÷ 42 = 2,050° C.

$MnS + 2MnO = SO_2 + 3Mn$ (+69,300 − 45,600 − 181,800) = −158,100 cals. 158,100 ÷ 42 = 3,781° C.

$Cu_2S + 2CuO = SO_2 + 4Cu$ (+69,300 − 20,300 − 75,400) = −55,700 cals. 55,700 ÷ 49 = 1,124° C.

These figures explain the facility with which copper matte is smelted and why the iron or manganese analogous processes do not exist. They account for the failure to desulphurise steel in the acid open hearth and Bessemer processes, and do account for why sulphur is not retained when manufacturing ferro-silicon in the electric furnace. They show that it is not necessary to postulate the formation of silicon sulphides to account for the observed facts.

Carbide-Oxide Reactions. Smelting Temperatures.

$Fe_3C + FeO = CO + 4Fe$ (+29,160 − 8,460 − 65,700) = −45,000 cals. 45,000 ÷ 39·4 = 1,117° C.

$Mn_3C + MnO = CO + 4Mn$ (+29,160 − 10,400 − 90,900) = −101,300 cals. 101,300 ÷ 39·4 = 2,571° C.

The practicability of the open hearth and Bessemer steel processes, and the non-existence of manganese analogues thereof, is shown by the above.

Iron-Silica Reaction. Smelting Temperature.

$$2Fe + SiO_2 = Si + 2FeO\ (+131{,}400 - 180{,}000) = -48{,}600 \text{ cals.}$$
$$48{,}600 \div 35 = 1{,}385^\circ \text{ C.}$$

The above is very important; it shows that at low temperatures, FeSi and FeO react, and that at high temperatures FeSi and FeO are *produced*.

The manganese analogue of the above reaction is accompanied by a heat *evolution* of only 1,800 cals., whilst the heat of union of SiO_2 and MnO is 5,400 cals. As a result slightly basic monosilicate of manganese is, in respect of its composition, the most stable of all known slags. Its heat of formation is one of the highest per unit of oxygen taking part. The reduction of monosilicate of manganese takes place as a whole, so that the corresponding silicide is formed. Thus the product produced in the electric furnace, silico-manganese, is almost free from carbide, and the commercial product is commonly about 31 per cent. Si and 63 per cent. Mn. When, in 1903, one of the pioneer French ferro-alloy makers told the author he had produced it, and asked his opinion as to whether it would be of any use to steel makers, he at once told him that it must be the ideal deoxidizing agent for steel. It possesses the additional and essential quality of being readily soluble in molten iron.

For years the author has been trying to get metallurgists to realise that whenever steel is produced low in oxygen content it always is, and always has been, due to added, or nascent silico-manganese, and nothing else.

The best steel makers add silico-manganese, instead of awaiting its formation from silicide of iron and carbide of manganese. The reason acid steels are better than instead of inferior to basic, is because ignorant steel makers cannot avoid its formation. The acid vessels provide for its formation at a greater rate than the formation of ferro-silicon and iron protoxide, and thus they produce passable steels.

That manganese by itself is not likely to be able to deoxidize steel effectively is shown by the following:—

$$Fe + MnO = FeO + Mn(+65{,}700 - 90{,}900) = -25{,}200 \text{ cals.}$$
$$25{,}200 \div 21 = 1{,}200^\circ \text{ C.}$$

The following calculations indicate the approximate temperatures at which the very highly refractory bases will become oxidizing to steel:—

$Mn + CaO = MnO + Ca(+90{,}900 - 131{,}500) = -40{,}600$ cals. $40{,}600 \div 21 = 1{,}933°$ C.

$3Mn + Al_2O_3 = 3MnO + 2Al(+272{,}700 - 392{,}600) = -119{,}900$ cals. $119{,}900 \div 56 = 2{,}141°$ C.

$Mn + MgO = MnO + Mg(+90{,}900 - 143{,}400) = -52{,}500$ cals. $52{,}500 \div 21 = 2{,}500°$ C.

Apparently these bases should be inert in the absence of catalysts.

Action of catalysts on bases:—

$Fe + K_2O = FeO + 2K(+65{,}700 - 98{,}200) = -22{,}500$ cals. $22{,}500 \div 28 = 803°$ C.

$Fe + Na_2O = FeO + 2Na(+65{,}700 - 100{,}900) = -35{,}200$ cals. $35{,}200 \div 28 = 1{,}257°$ C.

$2K + CaO = K_2O + Ca(+98{,}200 - 131{,}500) = -33{,}300$ cals. $33{,}300 \div 28 = 1{,}189°$ C.

$6K + Al_2O_3 = 3K_2O + 2Al(+294{,}600 - 392{,}600) = -98{,}000$ cals. $98{,}000 \div 77 = 1{,}273°$ C.

$2Na + MgO = Na_2O + Mg(+100{,}900 - 143{,}400) = -42{,}500$ cals. $42{,}500 \div 28 = 1{,}518°$ C.

$2K + MgO = K_2O + Mg(+98{,}200 - 143{,}400) = -45{,}200$ cals. $45{,}200 \div 28 = 1{,}613°$ C.

The above indicate that the alkalis will render (by means of catalytic action) these bases, even possibly magnesia oxidizing. In this connection the interesting results given in Appendix XII should be studied. The practicability of the Castner-Kellner aluminium process, and also of the Buettner magnesium process (*i.e.*, the reduction of $MgCO_3$ and Fe_2O_3 by C) can be accounted for.

The foregoing very crude calculations serve to indicate clearly the nature of the special problems with which steel producers and ceramists are faced.

Basic refractories must be free from alkalis, and, of course, oxygen compounds in the form of occluded gases. Neutral, or only moderately basic silicates, will probably only contain alkalis in the form of silicates, which, though very undesirable, will be less unstable. Lime or dolomite is only admissible where, as in furnaces, it is maintained caustic by means of being kept at a very high temperature.

Acid silicates, or silica, are absolutely excluded.

New refractories of great cost, such as zirconia, are not worth much investigation unless their heats of formation be extremely high, and their protoxides unroastable.

The silicates of alumina and magnesia, either neutral or basic, are clearly the most promising field, together with improved magnesite bricks. Neutral or basic silicates must be made from mixtures, and so treated that, at any rate, the working face *contains no acid portions*. For instance, a mixture of fireclay and alumina would be very little less harmful than the fireclay itself.

The final treatment of steel, which the author insists on as being essential, demands from the special neutral or basic refractories resistance to exposure to temperatures *not exceeding some 20° C. above the casting temperature of the steel.* The maximum temperature to be withstood is therefore *somewhat under 1,600° C.*

As to securing a suitable working surface on new refractories, reference to Appendix XI may be of interest.

Some ten years ago the author mentioned his ideas to the late Mr. S. B. Halcomb, the then technical managing director of the firm of Sanderson Bros. & Newbould, Ltd., Sheffield, and that gentleman recognised at once that they accounted for hundreds of observed facts, especially those relating to dead-melting, in a manner that no other theories had done, and it led to that gentleman and the author making arrangements to co-operate in making trials with a view solely to providing proof, or disproof, of the basic theories in question, without regard to whether the steels produced were usable, or even likely to be so. The main object was to provide preliminary evidence to justify expenditure on more costly trials, having in view producing evidence regarding the author's patented remedial process. As a result the author is enabled to furnish as appendices what he believes to be trial results of a quite unique value as demonstrating the course of chemical reaction in steel manufacture. These trials are of additional value as being conducted in an actual manufactory under conditions pertaining to actual manufacture.

The equilibria between slags, anhydrides, and the metal, which accompany rising temperature and liquefaction, are not repeated during falling temperature and solidification, and slags or gases in equilibrium with one phase of the metal cannot be in equilibrium with another phase of the latter during its change of phase: the heat contents of the two portions differ.

Passage through the colloidal state is similar, the colloidal state being regardable as a subphase. In the result phenomena of segregation, accompanied by recalescence, accompany the

solidification of the metal as it freezes in the mould, when it contains any dissolved oxides.

If the amount of oxygen be small, the ingot may not be spongy. If great, there is not time for full reciprocation of the reaction in the eutectic, and slags and gases are belched up. This phenomenon is termed "rising in the mould."

When oxygen saturated steel finds its way into a crack in a furnace hearth the action is exaggerated into the formation of "geysirs" even a few feet in height.

When steel is separated from the slag and contains any oxygen, as temperature is degraded slags are formed, and these cannot be in equilibrium with the metal at the isothermal lines of freezing in the mould. In the result segregation of slags, gases and elements, or more correctly metalloid-compounds, takes place. Further slags are held emulsified in the liquid portion. Usually the segregation has the effect of carrying the metalloid-compounds into the eutectic, save the silicide of manganese, which must be associated with the silicate of manganese. Sulphides of metals of the iron group being basic are affected by the influence of the basic oxides.

The segregation in steel ingots increases with their size, and is really due to the action of traces of FeO which have not been removed, owing to omitting the making of the finishing process separate from, and in a separate apparatus to, that employed for the refining process, *and absolutely invariably exposing the steel after leaving the furnace, to the action of a ladle lining, casting nozzles, and direct Bessemerising influences which would undo the perfection of perfect steel subjected to such obviously bad treatment.*

The segregation is great in ingots made for the cheap trade in ingots of moderate weight, and if large ingots were made of steel of ordinary "trade" quality they would be absolutely useless for any purpose. The steel maker is put under the severest call on his skill as a metallurgist in the manufacture of heavy ingots for forging into the costly inner tubes for large guns, such ingots exceeding 100 tons weight. Such gun tubes are forged hollow on a mandril, and are subjected to circumferential tension, and therefore the tensile test pieces are cut circumferentially. This is at right angles to the direction of forging which flattens out bubbles filled with slags or gases into elongated lenticular form.

So far as the author sees there should be no difficulty in shielding the steel absolutely from Bessemerising influences, but nothing can render the production of perfect steel possible, and its perfection being retained possible, save *its never coming in contact with any substance which is n t neutral or basic, from the commencement of its finishing process and thereafter. That is the*

problem which ceramists and steel makers must at once realise to be so important that it is almost a national sin to allow its solution to be impeded by considerations of time and capital. Quite apart from other serious action of acid ladle and tun-dish linings on the steel, there exists a defect that renders them incurably harmful. They become neutralised on the surface mainly by the formation of monosilicate of manganese. On emptying the ladle this thick glaze becomes very rapidly roasted, the protoxides of Mn and Fe being oxidized and becoming particularly effective oxide ORES. On next filling the ladle these alone are enough to blight a perfect steel. Their reduction increases the amount of glaze, and when this has increased to a certain degree it floats off in bulk, leaving the steel exposed to active silicate. Yet some steel makers are surprised at periodic epidemics occurring in their manufacture.

Ceramists should note the danger of traces of alkalies in the materials used in the final stages of steel manufacture. They may facilitate all sorts of dangerous, obscure, and subtle actions, perhaps nitrogenation of steel, the next greatest danger to oxidation.

Inasmuch as iron ores are mainly oxides, secondly carbonates, and thirdly sulphides, it stands to reason that it must be most difficult to make iron dead free from (1) oxygen, (2) carbon, (3) sulphur, and the author fears no contradiction from any practical steel maker who has essayed the problem.

In order to facilitate study of the course of chemical change it is always best to transmute analytical results into molecular percentages as is customary in the case of gas analyses. This is impossible in the case of matter in other phases, but almost as great facility is furnished by making use of a compromise the author has latterly adopted. He converts percentages by weight, into milligramme-atoms per 100 grammes. He chose this particular standard because the figures are not unwieldly, for one reason, but mainly, because the kilogramme calorie becomes, without alteration, the milligramme calorie per gramme.

In regard to a large portion of the matter contained in the appendices the author begs to thank the friends concerned for their generosity in allowing him to publish the results of trials which have cost them large sums, and heavy calls on the valuable time of the best experts on the directorates and staffs of their firms.

In conclusion the author cannot too strongly emphasise his opinion that the question of the refractories employed in contact with molten steel is not a side issue, but in the final stages of steel manufacture the most actually vital main issue, deciding its quality, in regard to freedom from dangerous defects.

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Appendix A.

Foreword re Study of the Course of Chemical Change.

In putting before members of The Ceramic Society the hitherto unpublished results of the costly trials, particulars of which are given in this appendix, the author would point out that the goodwill, his possession of which enabled him to get these trials made, has led to, and been partly created by, very frank and critical discussions with the "gloves off," so to speak, with the picked expert chiefs and technical members of the staffs of some of the very greatest steel manufacturing firms, both British and foreign; that is to say, with men usually his superior in knowledge and intellect. In spite of this, he has, as a specialist, very frequently found it necessary to issue

warnings, which have been appreciated, with regard to the manner in which to avoid pitfalls, and extract the maximum of knowledge concerning the course of chemical change as revealed by trials of the class. It may not be out of place to indicate, to some of the members of this Society, some of the class of warnings needed. So many busy men's minds are troubled by business routine that they have not the chance of acquiring the habit of bearing in mind analogous trial results when considering the data yielded by a particular trial, and thus they fail to look out for and appreciate those subtle influences which, though paramount, are often obscure and, it may be, not directly perceptible at all.

He has been chaffed about his persisting in using several places of decimals in the figures he has arrived at in transposing the results of analyses, on the ground of the coarser limits imposed by unavoidable errors in the figures arrived at by analysts. One should never dock figures in the course of a calculation. The effects of such docking may readily become cumulative to a serious extent and give rise to substantial error. It takes far more time and trouble to estimate to what extent it is prudent to dock figures.

He has found analysts, as a class, sadly too prone to attribute to errors in analysis (even their own accurate painstaking work) results which seem to be opposed to, or very different from what they have been taught to expect, or believe in. This has caused metallurgists frequently to make discoveries which chemists ought to have anticipated. There is little or no excuse for errors in analysis, due to faulty weighing, having regard to the high perfection of chemists' balances. If a series of similar analyses be made *by the same skilled chemist, as they always should be*, then whatever the actual percentage of error, due to his method or personal equation, then *that percentage of error should vary very little throughout the series, and have very little effect on the smaller differences between members of the series, that is to say, on the amounts of chemical changes which have occurred.* We are often chiefly concerned by the smaller changes and smaller differences. In nothing is decimal docking so serious as in such cases.

The occurrence of chemical change alters the basis on which percentage is calculated, and hence, by means of careful trial and error methods, all percentages must be transposed into percentages on the original base. Apparent, but not actual, losses or gains of an element may be due to concentration, or dilution in a charge which has undergone corresponding shrinkage or growth. Often, they may furnish the key to the latter.

Again, colloidal segregation may cause a test not to represent mean analysis. By way of example, the author will mention cases which may concern real or illusory chemical change.

It frequently happens that when spoon tests are taken hurriedly from the surface of the bath in the basic Bessemer convertor (the blow being stopped and the convertor tipped for a moment for the purpose) that a definite rise of carbon is shown on analysing the tests. Now this must not be attributed to error of analysis even at the analyst's own suggestion. We should look into the following likely or unlikely contingencies:—(*a*) Carbon derived from badly calcined or raw limestone, (*b*) shrinkage of the charge due to slag formation, (*c*) segregation of carbon owing to reciprocation of its oxidation as the gases are relieved of pressure in rising through the bath, (*d*) segregation due to slag at the surface being different from the nascent internal slag rising through the steel.

An oxide may be formed at the bottom of the bath where the mass action of oxygen is greatest, and reduced again at the top where it is least, and this may occur at a greater rate than that at which the metalloid compound oxidized at the bottom, and reformed at the top of the metal bath, can be redissolved by the latter.

When silico-manganiferous foundry iron is run into a ladle containing peroxide of iron ore (with a view to fitting it for use in the basic steel process), it is frequently found that a small loss of carbon percentage is shown, and, in most cases, it will be found to be due to dilution. Roughly, the iron gain is twice the silicon loss, and cuts out that of manganese.

One must remember that the rate of solution of different solutes in a given common solvent is not the same, and that the reacting surfaces of slag, crucible and metal, are in definite finite ratio to one another, and one must also bear in mind the law of dilution; then one appreciates why the deoxidation of crucible steel is such a very roundabout action.

It is of great importance to remember that whereas only limited reaction might serve to glaze the surface of the crucible, and bring it into equilibrium with the steel, and also to create a small amount of slag in equilibrium with the steel, at the triple junction of the slag, metal and crucible surfaces, equilibrium may be impossible and intense chemical action may occur. In the crucible steel process one very nearly attains a three-pair equilibrium indicated by the initials S—M, S—C, and M—C. But one cannot attain the triple equilibrium S—M—C. In the result, the crucible steel maker "accepts the trouble," that of crucibles cut at the junction of metal and slag, as part of the

inevitable cost of his manufacture, and uses the crucibles twice or three times, with smaller charges each "round," and then philosophically throws them away. Not so the Bessemer or open hearth steel manufacturer, who, in his desire for cheapness, will try to go counter to the laws of Nature, and try to conduct the two most opposite final stages of manufacture in one process, viz.: refining, and eliminating the refining agent. He attempts to sacrifice quality to cheapness, and, like most people who "ask for trouble," he gets it. He gets neither quality nor cheapness. A furnace and methods suitable for the refining process must be inverse as to design, and the conditions suited for the inverse process.

The author's main invention concerns the final process. He cuts out continuous exothermal catalytic oxidation by means of employing a slag which is alike unroastable and irreducible. Analogous refractories which will not be fluxed by such slags require evolution.

Similar materials are used for making crucibles, and lining steel casting ladles. The conditions though are dissimilar. In the former heat is passed through the refractory, and the temperature of the charge (and refractory) is ascending. In the latter the refractory is heated internally by, and cools the charge. In the former the slag is protected from oxidation, in the latter it is exposed to it. As a ladle empties, "occluded" gases in the metal are relieved of pressure, and the ratio of slag and crucible surface to weight of metal is a cumulatively increasing one.

One cannot expect uniform action of the entire surface of a large ladle, and this may give rise to local inequality of composition where the less soluble compounds are concerned, and, during emptying, eddy actions may wash these portions through the nozzle, giving rise to irregular ingots of a series. In order to facilitate equable solution, it may be necessary whilst dead melting, to stir the steel, say, by local "pinch effect."

Granted all other conditions being absolutely identical in the case of two charges, made in two open hearth furnaces, the one of the tilting, teemed type, and the other of the fixed, tapped type, the quality of the ingots produced must be substantially affected. The author is surprised at having never heard or seen a reference to this. In the former case the hottest portion of the furnace charge enters the ladle first, thus causing the charge in the ladle to be at a fairly uniform temperature, and, in consequence, the latter ingots to be cast from much more colloidal steel than the first. In the latter case (tapped charge) the coolest steel enters the ladle first and the

temperature gradient in the ladle is similar to that in the furnace. The cooler furnace-steel issues first from the ladle, and thus the temperature gradient of the steel issuing from the ladle nozzle is much less steep than in the former case.

Plug and nozzle troubles are due to "ladle action" being intensified by the heavy friction of the stream eroding them. They weld readily owing to the fluxing of the surfaces. This is a pressing problem for the ceramist.

Broadly speaking, steel manufacture originated from abortive attempts to make iron. It passed through three stages. (1) Refined iron was cemented into blister steel, crude iron carbide. (2) Huntsman melted this at low enough temperature to deoxidize it provided he allowed heavy formation of silico-iron. (3) Heath noticed that Swedish iron produced better steel than British iron of similar analysis, and guessed this to be due to the Swedish ores being manganiferous, and this favourably influencing the quality of the iron, from which manganese had been removed in the refining process. He therefore used spiegeleisen, then termed by him "carburet of manganese." He thus was able to produce dead melted steels of lower carbon, and higher fusion point, and lower silicon, than Huntsman.

Appendix I.

A Note on the old Sheffield "Best Sheffield Double Refined Cast Steel" Process.

About 60 or 70 years ago, before the era of cheap steels inaugurated by the evolution of the Bessemer process, the customers of steel makers did not begrudge paying more for a better article, especially where the cost of the bar steel was but a small fraction of the cost of producing a finished article, such as a first-rate ivory-handled razor.

The old Sheffield crucible steel makers did not have their perception of subtle differences of quality blinded, or suppressed, owing to over-confidence in ill-grounded theories of chemists, and their goodwill was built up on their being guided in their metallurgy by sound natural instincts, founded on close touch with Nature's operations. They escaped being led astray by text books. In the result, they evolved a costly duplex process, now almost extinct, remembered by the few, and never even heard of by many steel makers of to-day. Every advance in knowledge serves only to show good reason why razors made in those days are treasured heirlooms almost, and possess superb qualities that the modern more "flashy" article does not. In the light of modern knowledge, the process was scientifically correct and logical, and the moral pointed by it

cannot be too strongly urged. Whereas in the ordinary crucible process, bar iron covered with rust, hammer, or roll scale, and other oxides, together with charcoal, form the material used for the charges introduced into the crucibles; in this duplex process the best and costliest Swedish bar iron, which had been converted into steel by the cementation process, that is to say, blister steel, was used, and, so the author has been informed, these costliest brands of iron on conversion yielded a subnormally blistered blister steel. Now the ores from which the bar iron was made were manganiferous, and, although the manganese was puddled out, doubtless the bar iron contained less iron oxides and silicates in its pores, in consequence of the part played by the manganese in the puddling process. Then again, the cementation process resulted in a steel very low in oxides. *The charge was composed of material quite subnormal in oxygen content.* The charges were melted together with a little ferro-manganese in "first round," *i.e.*, new pots, and, as soon as freely melted, *i.e.*, not fully dead melted, the steel was cast into chill moulds of small section.

The moment it was safe to do so, the ingots were knocked out of the moulds, and plunged nearly white hot, into running cold water in a bosh, and were chilled down. Being very brittle, they were broken by means of sledge hammers, into pieces of a size suitable for remelting.

This treatment produced many important effects. It resulted in the steel being rendered very low in oxygen by its being somewhat siliconised, and nearly stable silicates formed within it, and its carbon being combined, and the steel rendered very homogeneous. *Above all, the skin of the interior of the crucibles had been brought into close approach to chemical equilibrium with molten steel.* The crucibles were returned to the furnace, and then charged with materials prepared, in the manner just described, the day previous. These charges were re-melted, and did not require much dead melting, and, in the result, oxygen-free steels of lower silicon content than the ordinary process admitted of being made, were produced. The fact that in the ordinary course, absence of oxygen was only attainable, or attained, in high silicon steels, led many steel makers to regard silicon as a good, instead of bad, alloy, *qua* alloy.

Appendix II.

Note on the Action of Silica Hearths on Molten Steel.

During the period 1894 to 1897 (whilst the author was in charge of the steel producing plant at the Vickers' works) it

was observed that in newly-built (acid open hearth) furnaces, which had, of course, had clean hearths fritted in, or in repaired furnaces, which, on restarting, had had the old hearths slagged and hacked away, and large amounts of silica freshly fritted in, the steel made the first time of charging was of markedly inferior quality, in spite of the fact that the furnace, as a heat transmitter, was at the very zenith of its working. This first led the author to suspect that silicic acid was an oxidizing agent for iron. As a result of these observations, unless first heats could be used for castings, of a nature which it was legitimate to dose with aluminium, or for ingots for the firm's own consumption, for bars for slagging furnaces, or other purposes where it was merely desirable that they should form good scrap "returns," when worn out, the first heats were carefully made, and then cast into moulds, and the ingots used for remelting. The cost of such first heats were regarded as part of, and charged to, the cost of construction or repairs, as the firm's goodwill did not admit of taking the minutest risks in regard to the prime quality of their output.

Next, it was noticed that where a local defect in a hearth had been heavily patched, that during the "boil" (carbon reaction), either the "boil" was sluggish, or absent.

Again, it was observed that in the Harveyising process, if the rough machined backs of the armour plates were overheated, they were siliconised to an appreciable depth, and were covered with an adherent glazed slag. The backs of the plates were covered by a layer, of a few inches in depth, of the quartzite sand used for the melting furnaces; above this, by a dry course of brickwork, and finally, above this, by a layer of wheel-swarf. Direct oxygenation was thus excluded in a similar manner to that adopted in the old-fashioned cementation furnaces.

Appendix III.

Note on the Course of the Crucible Steel Process.

Copy extract from the Author's Trials Note Book.

Trials as to course of crucible steel process made May 4th, 1909, at the Darnall Works of Messrs. Sanderson Bros. and Newbold, Ltd., in the presence of Sydney Broughton Halcomb and Alleyne Reynolds.

Objects of trial.—To test the author's theories as to steel being oxidized and siliconized owing to iron and manganese being oxidized by unneutralized silicic acid, and, in turn,

deoxidized by the action of dissolved carbides and silicides, derived from the reduction of the free silicic acid of the pot. Further to endeavour to imitate the conditions which would obtain in a pot actually composed of nearly pure silica.

Precautions taken.—It was obviously not feasible to take tests from the pots from time to time, and in lieu of this several pots from the same batch (*i.e.*, mixture), and identical charges must be used. Further, mild charges should, owing to their high fusion point, illustrate the reactions best.

Pots employed.—Nine white clay pots were used of the following analysis:—

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alkalies	Loss on Ignition
50·93,	37·36,	6·16,	0·23,	0·59,	1·56,	4·28—101·11

Charges used.—A Swedish Bessemer ingot was forged into bars and cut up, the pieces carefully averaged (tops and bottoms) and nine "weighs" of 50 lbs. each were made.

Analysis of charges.—Analysis of bars (after forging) gave the following results:—C, 0·44 per cent.; Si, 0·038 per cent.; Mn, 0·290 per cent.; P, 0·026 per cent.; S, 0·003 per cent.

Furnace.—A 12-hole Siemens gas furnace, second round of pots. The nine pots, with three pots of file steel, were placed in the furnace as under:—Nos. 1, 2, and two file steel, in cooler working zone. Nos. 3, 4, 5, 1A, 2A, 3A, 4A and one file steel in hotter zone. Nos. 1, 2, 3, 4, 5 were simply charged with 50 lbs. of the bar steel, and allowed to form slags naturally. Nos. 1A, 2A, 3A, 4A were charged with 25 lbs. bar steel, and then 1½ lbs. of pure ganister lumps (about 98 per cent. SiO_2), and then the balance of 25 lbs. bar steel.

Time of melting.—All nine pots were charged within a few minutes of each other, and took from 2½ to 2¾ hours for the charges to become just melted.

Moulds used.—2¾ in. square moulds were used for the ingots.

Mops.—Perfectly clean "mops"[1] were employed, and marked clean buckets were provided, into which the respective "mops" were put after using, so that absolutely all slag mopped could be collected and accurately weighed.

Procedure adopted.—Before teeming, each pot was mopped quite free from slag. No. 1A was teemed as soon as melted; No. 2A, 30 minutes after steel molten; No. 3A, 60

[1] The mops consist of steel bars with a big club end on them, and by freezing the slag on to the club end of the mop, it is removed from the steel.

minutes; No. 4A, 90 minutes. No. 1A ingot rose. No. 2A ingot, very slight traces of rising occurred. No. 3A ingot rose slightly. No. 4A ingot rose slightly. No. 1 pot, after mopping, a $9\frac{1}{4}$ lb. ingot was cast, which rose. Then $\frac{1}{2}$ lb. ferro-manganese was added to the charge in the pot, the lid put on, and the pot was returned to the furnace for a further 15 minutes' heating, when it was pulled out, mopped and teemed into an ingot marked 1X. This ingot rose very slightly, and weighed only $35\frac{1}{4}$ lbs., that is to say, only a total of $44\frac{1}{2}$ lbs. ingots was obtained from this pot. No. 2 ingot showed minute trace of rising. No. 3 ingot showed trace of rising. In No. 4 pot, after its charge having been molten some 80 minutes, a leakage of slag occurred, through a small round hole at the slag line of the pot. After careful mopping an ingot of $9\frac{1}{4}$ lbs. weight was cast. No rising was noted Half-pound of ferro-manganese was added to the balance of the charge (which now was below the hole in the pot), and the lid was put on and the pot returned to the furnace for 15 minutes, when it was again pulled out, mopped, and teemed into an ingot marked 4X. This ingot did not rise. No. 5 pot. Ninety minutes after the charge was molten the lid was removed from the pot, which was left in the furnace uncovered for 15 minutes, or a total of 105 minutes after becoming molten, and then the charge was mopped and teemed. I find no note as to the behaviour of this ingot in regards to rising, and presume that it did not rise.

Condition of pots.—Somewhat sweated, but not markedly cut, with the exception of the hole in No. 4 pot at the original slag line.

Slags.—The heavier (bulkier) slags showed a dark glossy surface, enclosing white and mottled portions, apparently segregated on cooling.

Treatment of slags.—In each case the whole was reduced to a fine powder, mixed, quartered, and generally treated by assayists' methods of securing a fair sample for analysis. They contained small globules of metal which were separated out by means of a magnet previous to analysis.

Analysis of ingots and slags.—

TABLE I.

Pot No.	Ingot per cent on Charge	Analysis of Ingot					Slag per cent on Charge	Analysis of Slag			
		C	Si	Mn	P	S		SiO_2	FeO	Al_2O_3	MnO
Charge	100·0	·44	·038	·290	·026	·003	—	—	—	—	—
1	89 0	·38	·069	·160	·028	·006	·3125	49·64	6·13	25 25	15·60
2	97·5	·38	·060	·145	·026	·008	·7500	67·51	5·77	15 06	9·24
3	97·5	·40	·105	·145	·029	·007	3·500	59·82	4·70	21·38	11·78
4*	97·0	·38	·080	·120	·029	·008	2·8125*	62·02	5·25	19·90	11·01
5	100·0	·40	·110	·110	·027	·013	5·000	61·17	4·20	21·00	12 90†
* No. 4 Pot leaked at slag line.							† No. 5 Slag contained 0·15 per cent. S.				
Charge	100·0	·44	·038	·290	·026	·003	3·000	98·00	—	—	—
1A	97·0	·39	·102	·150	·027	·006	6·6875	80·11	2·25	10·20	5·25
2A	96·0	·40	·085	·150	·028	·011	7·6875	76·75	3·02	11·67	6·90
3A	101·0	·38	·105	·100	·027	·011	7·0625	71·35	4·54	12·97	7·33
4A	101·5	·38	·090	·095	·027	·010	7·500	78·80	3·65	11·00	4·91
1.		·380	·069	·160	·028	·006					
Added		0·95		1·187							
Total		·475		1·347							
1X		·410	·110	1·145	·033	·009	·789	65·71	6 70	14·10	12 72
4		·380	·080	·120	·029	·008					
Added		·084		1·045			Leaky		Pot		
Total		·464		1·165							
4X		·420	·120	1·105	·031	·011	·876	48·63	5·17	26·00	19·00

Conversion of table into milligramme atoms of the elements.—In order to enable the occurrences to be better understood the above figures were converted into milligramme atoms per 100 grammes of charge. That is to say, ·012 per cent. carbon, ·0284 Si, ·055 Mn, and so on are taken as units respectively.

TABLE II.

MILLIGRAMME ATOMS PER 100 GRAMMES CHARGE.

Pot No.	In Steel			In Slag			
	C	Si	Mn	Si	Fe	Al	Mn
Charge	36·6667	1·3380	5·2727	—	—	—	—
1	31·6667	2·4295	2·9091	2·5683	0·2116	1·5442	0·6866
2	31·6667	2·1127	2·6364	8·3829	0·6019	2·2104	0·9761
3	33·3333	3·6972	2·6364	34·6690	2·2879	14·6438	5·8072
4*	31·6667	2·8169	2·1818	28·8794	2·0536	10·9528	4·3614
5	33·3333	3·8732	2·0000	50·6374	2·9207	20·5489	9·0847
* Leaky pot							
Charge	36·6667	1·3380	5·2727	48·6755	—	—	—
1A	32·5000	3·5915	2·7273	88·6980	2·0927	13·3488	4·9451
2A	33·3333	2·9930	2·7273	97·6847	3·2290	17·5864	7·4711
3A	31·6667	3·6972	1·8182	83·4287	4·4596	17·8845	7·2914
4A	31·6667	3·1620	1·7273	97·8477	3·8074	16·1448	5·1867
1	31·6667	2·4295	2·9091	—	—	—	—
Adn.	7·9166		21·5818				
Total	39·5833		24·4909				
IX.	34·1667	3·8732	20·8182	8·6815	0·7436	2·2019	1·4297
4	31·6667	2·8169	2·1818	—	—	—	—
Adn.	7·0000		19·0000				
Total	38·6667		21·1818				
4X.	35·0000	4·2254	20·0909	7·0530	0·6299	4·4571	2·3443

The figures in Table 2 not being quite adequate, a further table, Table 3, was worked out showing the gains and losses of atoms in the steel, and the sources of those in the slag. The mere fusion by fluxing of the crucible would involve alumina contained in the slag being accompanied by SiO_2 and Fe_2O_3, which later would be and was reduced to FeO. If by iron, of course the amount of FeO would be 50 per cent. greater than the Fe_2O_3. For this reason, to avoid confusion, elements were given instead of the oxides, the ratio of the elements in the crucible being (in atoms) $\frac{Si}{Al} = 1·1533$, $\frac{Fe}{Al} = ·10545$. The difference between the figures thus arrived at,

TABLE III.

Pot No.	Milligramme Atoms per 100 Grammes Charge											
	Steel		Si in Slag				Fe in Slag			Mn in Slag		
	C Lost	Si Gained	1·1533 x Al	From Ganister	Difference	Total	·10545 x Al	Difference	Total	Lost by Steel	From Pot	Total
1	5·0000	1·0915	1·7809	—	0·7879	2·5688	0·1628	0·0488	0·2116	2·3036	(To) -1·6770	0 5866
2	5·0000	0·7747	2·5434	—	5·8395	8·3829	0·2331	0·3688	0·6019	2·6363	(To) -1·6602	0·9761
3	3·3333	2 3592	16·8891	—	17·7799	34·6690	1·5442	0·7437	2·2879	2·6363	3 1709	5·8072
4	5·0000	1·4789	12·6321	—	14·2473	28·8794	1·1549	0·8987	2·0536	3·0909	1·2705	4·3614
5	3·3333	2·5352	23·6984	—	26·9390	50·6374	2·1668	0·7539	2·9207	3·2727	5·8130	9·0857
1A	4·1667	2·2535	15·3955	48·6755	24·6270	88·6980	1·4076	0·6851	2·0927	3·5454	2 3997	4·9451
2A	3·3333	1·6550	20·2482	48·6755	28·7610	97·6847	1 8513	1·3777	3·2290	2·5454	4·9257	7·4711
3A	5·0000	2·3592	20·6742	48·6755	14·0790	83·4287	1·8903	2·5693	4·4596	3·4545	3·8469	7·2914
4A	5·0000	1·8240	18·6208	48·6755	30·5520	97·8477	1·7025	2·1049	3·8074	3·5454	2 6413	5·1867
1X	5·4166	1 4437	2·5395	—	6·1420	8·6815	0·2322	0·5114	0·7436	3·6727	(To) -2·2430	1·4297
4X	3 6667	1·4085	5·1405	—	1·9125	7·0530	0·4700	0·1599	0·6299	1·0909	1·2534	2·3443

and the totals of the elements, could only be reduced and reoxidized elements whose presence in the slag was due to chemical reaction between the crucible and the steel.

Composition of the pots.—The composition of the pots in milligramme atoms per 100 grammes of pot works out as under:—$SiO_2 = 843{\cdot}21$; $Al_2O_3 = 365{\cdot}56$; $Fe_2O_3 = 38{\cdot}55$; $CaO = 4{\cdot}10$; $MgO = 14{\cdot}62$; $Ak_2O = 19{\cdot}90$ where Ak = mean of Na and K. That is to say, Ak_2O is taken as possessing an atomic weight of 78·2, that of Na_2O being 62·1 and of K_2O being 94·3.

Presumptions as to actual composition of the pots.—We will first presume that the clay was mainly a hydrated bisilicate of alumina, that $2 \times 365{\cdot}56\ SiO_2$ or $731{\cdot}12\ SiO_2$ was combined with it (Al_2O_3), and that the silicates of the alkaline earths and alkalis were monosilicates. The composition then becomes: $(SiO_2)_2\ Al_2O_3 = 365{\cdot}56$; $SiCaO_3 = 4{\cdot}10$; $SiMgO_3 = 14{\cdot}62$; $SiAk_2O_3 = 19{\cdot}90$; $SiO_2 = 73{\cdot}47$; $Fe_2O_3 = 38{\cdot}55$.

Action of steel on Fe_2O_3 in pot.—The action of the molten steel on Fe_2O_3 would be that at once the Fe_2O_3 would be reduced to FeO by R where R = Fe or Mn, the latter predominating, and this would combine with SiO_2 to form at least a monosilicate in which the SiO_2 remaining would be dissolved. The equation resulting would be as under:—$73{\cdot}47\ SiO_2 + 38{\cdot}55\ Fe_2O_3 + 57{\cdot}775\ R = 57{\cdot}775\ SiRO_3 + 15{\cdot}695\ SiO_2 + 38{\cdot}55$ Fe. Such a composition is that of an acid open hearth furnace slag at the height of the oxidizing period. It should be noted that the above calculations are only applicable strictly to a single clay, or a mixture of clays which have been sufficiently incipiently fused for the mixture to become a compound. Otherwise each separate clay of which the mixture is composed must be considered separately in a similar manner.

Such pot might be continuously oxidizing.—The total weight of Fe_2O_3 in the pot, which would weigh some 25 to 28 lbs., would be far in excess of that of the Fe_3O_4 scale on the charges. Further, as shown by the slag roasting trial described,[1] the Fe_2O_3 would be reduced to FeO throughout, and hence clearly the pot would act similarly to an open hearth slag in catalytically transferring oxygen and sulphur through its walls.

Carbon reaction confined to melting down period.—The carbon lost varied from 3·3333 to 5·0000 atoms quite independently of whether the steel were only just molten or held some 30 to 90 or more minutes in the molten state. This very distinctly suggests that the carbon reaction took place practically solely during melting down, where crucible reaction had little

[1] Appendix IX.

or no influence, and the variation was solely due to variation in the amounts of Fe_3O_4 present as scale on the charges, and also, of course, possibly on the temperature at which the physical conditions admitted of the reaction, that is to say, on whether solely CO, or partly CO and some CO_2, were evolved in reduction of the Fe_3O_4.

Formation of silicides and silicates, Pot 1.—Apart from the above general observation, it is necessary to consider each case in somewhat minute detail. In the case of Pot 1 the first point to note is that of 2·3636 atoms of Mn lost by the steel 1·6770 atoms *went into the pot* and only 0·6866 found their way in the slag. In this connection one must bear in mind how silicates and silicides may be formed.

Formation of silicides and silicates (general).—

(*a*) Reduction of basic oxide by silicon or silicides thus:—

$Si + 3RO = SiO_2RO + 2R$, *or*

$3Si + 3RO = SiO_2RO + 2RSi$,

$2Si + 5RO = (SiO_2)_2RO + 4R$, *or*

$6Si + 5RO = (SiO_2)_2RO + 4RSi$.

(*b*) Reduction of silica by base-forming element:—

$2R + 3SiO_2 = 2SiO_2RO + Si$, *or*

$3R + 3SiO_2 = 2SiO_2RO + RSi$,

$2R + 5SiO_2 = 2(SiO_2)_2RO + Si$, or

$3R + 5SiO_2 = 2(SiO_2)_2RO + RSi$.

It should be noted that in type (*a*) for each atom of Si oxidized two atoms of R are reduced, and in the case of type (*b*) for each two atoms of R oxidized one of Si is reduced. In both cases for each atom oxidized one molecule of monosilicate slag is formed, whilst in case (*a*) for each two atoms oxidized one molecule of the bisilicate slag is formed, and in case (*b*) for each atom oxidized one molecule bisilicate slag is formed.

Review Pot 1.—One may assume that after the carbon reduction of the scale during melting down (and when the latter was not in solution) and after fusion of the metal and reduction of the scale to FeO and the solution of the latter in the steel, the amount of O in FeO at no time would exceed 6 atoms or saturation point.[1] In Pot 1, 1·0915 Si was gained by the steel involving that 2·1830 R(R = Fe or Mn) had been oxidized, and the presence of 0·1628 Fe in the "Pot slag" would involve a further 0·0814 R having been oxidized. Thus these two items demand a total of 2·2644 R having been oxidized. (Note.—By "Pot slag" is meant molten but otherwise unchanged pot material, and the other constituents of the slag will be referred to as "steel slag.") The

[1] Vide Carnegie Memoirs, Iron and Steel Institute, Vol. VII., p. 81.

Mn lost was 2·3636, and the iron in the "steel slag" was ·0488, making a total of 2·4124 R oxidized, the difference or 0·148 being easily accounted for by reoxidation of silicides. The "steel slag" was of the composition ·7879 SiO_2, ·7354 RO, or ·7879 SiO_2, ·0488 FeO, ·6866 MnO, the bulk of the manganese lost having served to neutralize the surface of the pot, and the total lost being enough to have siliconized the steel 1·1818. The difference between this figure and 1·0915 or ·0903 represented *reoxidized* Si.

Pot 2.—On balance there was less gain of Si to the extent of ·3168. There was more loss of Mn to the extent of ·2727, and ·2895 more Mn had formed "steel slag," and ·0168 less Mn had gone into the pot. There was a growth of ·0703 in Fe in "pot slag" requiring formation of ·0351 RO (which might adhere to the pot whether R = Mn or Fe). The steel was practically deoxidized. This clearly points to reoxidation of SiR, mainly Si Mn. The composition of the "steel slag" was 5·8395 SiO_2, 1·3449 RO, *i.e.*, 5·8395 SiO_2, 0·3688 FeO, 0·9761 MnO. The total slag (which we will term henceforth "general slag," was thus more acid than the pot. This points to SiO_2 being dissolved by the "general slag" and the cutting of the pot at the slag line. In other words, the *free* silica of the pot had more affinity for the complex "general slag" (molten) than the pot (solid).

Pot 3 and subsequent ones.—The total Mn in the slag was more than the total charged in the steel, and this fact, coupled with the tremendous growth of slag, is proof positive that the neutralized surface of the pot on being subjected to a higher temperature was fluxed and floated to the slag, and that this fluxed matter included that formed by the previous charge worked at a lower temperature. Growth of silicon recommenced, the steel was less deoxidized, and the absence of loss of Mn indicates that Fe had been the reducing agent for the silica reduction of the rebared acid surface. Probably this great growth of slag had only occurred towards the end, for some Mn loss took place in the subsequent pots.

General.—The "steel slags"[1] were as under:—

No. 1	SiO_2 = 1·073 RO	SiO_2 in steel slag = 0·442	SiO_2 in pot slag
No. 2	,, = 4·342	,,	,,	,,	= 2·296	,,	,,
No. 3	,, = 2·713	,,	,,	,,	= 1 053	,,	,,
No. 4	,, = 2·709	,,	,,	,,	= 1·128	,,	,,
No. 5	,, = 2·738	,,	,,	,,	= 1·133	,,	,,

1 ("Non Pot Slags" including effects of previous charge). The "steel slag" formed in No. 1 was practically a monosilicate, and this was followed by deoxidation of the steel by Si Mn, and at the slag line a considerable solution of SiO_2 by the slag, thus locally neutralizing the crucible, and accounting for the limitation of such cutting action. When the fluxing of the main surface of the pot commenced and as temperature rose the "steel slag" became increasingly acid, and its ratio to the "pot slag" nearly constant. Reductions and oxidations nearly balanced leaving the steel less perfect than at No. 2 pot.

These figures again illustrate the probable correctness of the conclusions come to above.

No. 1A *to* 4A.—It is difficult to form definite conclusions in regard to these. The free SiO_2 during melting down would be brought into contact locally with the pot walls and locally flux them, so that whilst one reaction proceeded in one locality another might in another. In No. 1A Si gained was 2·2535, which would require the formation of 4·5070 RO, and 1·4076 Fe in "pot slag" would require a further ·7038, making a total of 5·2018 RO, against which we have only 0·6851 FeO in the "steel slag" and 2·5454 Mn lost by the steel, or a total of 3·2305 RO due to these sources. In 2A a loss of some Si but of no Mn occurred. This was followed in 3A by a gain of ·7042 Si, which would require the formation of 1·4084 RO, of which ·9191 is accounted for by loss of Mn. In 4A there was a loss of ·5352 Si and ·0909 Mn. The total FeO in the "steel slags" was greater than in Nos. 1 to 5. Apparently about the whole of the surface of the pots originally acted on by the previous charge was fluxed away. No ingot was perfect, the best was No. 2A, and the next best No. 4A, in fact the oxidation was inversely proportional to the siliconization. No. 1A to 4A were exposed to more rapid impact of heat than Nos. 1 and 2, Nos. 1A and 2A being melted quicker than Nos. 1 and 2. The following calculations were made for comparison with those relating to Nos. 1 to 5:—

No. 1A	SiO_2 in steel slag	=4·552 RO.	SiO_2 in steel slag	=1·600	SiO_2 in pot slag			
No. 2A	,, ,,	=3·250 ,,	,, ,,	=1·424	,, ,,			
No. 4A	,, ,,	=4·190 ,,	,, ,,	=0·681	,, ,,			
No. 3A	,, ,,	=1.428 ,,	,, ,,	=1·641	,, ,,			

NOTE:—In the above, "steel slag" includes MnO or FeO from the previous charge, and excludes the added ganister.

Pots 1X *and* 4X.—In cool pot 1X 1·4437 Si was acquired, requiring 2·8874 RO to be formed, and the ·2322 Fe in the "pot slag" would require a further formation of ·1161 RO, or a total of 3·0035 RO. Against this 3·6727 MnO alone was formed, 2·2430 of which adhered as "silicate" to the pot. The heavy loss of carbon, and the large amount of SiO_2 in the "steel slag" point to more Si having been reduced and oxidized again by FeO dissolved in the steel, and the large carbon loss would make it appear as if considerable Bessemerization had taken place. In case of the hotter charge in No. 4X it would appear as if carbon had played a part and also iron to a considerable extent, for the RO formation due to increase of 1·4085 Si would be 2·8170 and due to ·4700 Fe in pot slag would be ·2350 or a total of 3·0520 RO, only 1·0909 of which

was supplied in the form of MnO. The "steel slags" (including in 4X that from previous charge) were as under:—

No. 1x	$SiO_2 = 3{\cdot}164$ RO.	SiO_2 in steel slag $= 2{\cdot}418$ SiO_2 in pot slag
No. 4x	,, $= 0{\cdot}763$ RO.	,, ,, $= 0{\cdot}372$,, ,,

The great difference between the figures indicates how much more the hotter pot had been neutralized than the cooler one by the previous charges. It must be borne in mind that the "pot slag" figures apply to a mixture of clays, and that therefore the alumina carried into the slag may be that due to one or more of the clays used, and that in the early stages one of the clays may be attacked, and later the others. If possible a single-clay pot[1] should be used in such cases (of trials). The great losses of C and Mn in these two cases, losses incurred in only 15 minutes, are not fully and satisfactorily explained.

Appendix IV.

Reduction of Silica by Iron and Manganese.

Copy extract from the Author's Trials Note Book.

Trials made November 24th, 1909, at the Darnall Works of Messrs. Sanderson Bros. & Newbould, Ltd.

Object of trial.—To endeavour to prove or disprove A.R.'s theories as to endothermic formation of silicates by the action of iron or carbide of iron, and of carbide of manganese on silica.

Pots used.—Clean new plumbago pots purchased from the Morgan Crucible Co., Ltd.

No. 1 trial pot.—22½ lbs. of ferro-manganese and 15 lbs. of Calais sand were placed in the pot, which was covered by an ordinary clay pot lid, and placed in No. 1 gas furnace at 2-38 p.m. Contrary to expectations the metal did not readily melt, the sand, which filled the interstices between the pieces of metal, required intense and prolonged heat to bring the metal to fusion temperature. At 4-30 p.m. the sand, which had remained quite loose in the pot, began to show signs of fusion where in contact with the metal, and by 5-20 p.m. there were three distinct layers over the bath. Next to the metal was a fluid slag, above this was a thick layer of sandstone-like character, the penetration of which by a potter bar required some force, and on the top of this layer some of the sand remained in its original dry (loose) condition. At 5-35 p.m.,

[1] Not made from a mixture of clays.

although there was some difficulty in deciding the point owing to detached portions of the sandstone-like substance obstructing the potter, it was judged that the metal was completely molten. The slag was therefore drawn off at 5-45 p.m., and the metal was teemed in thin layers on to cleaned floor plates. It proved to be "clear melted," *i.e.*, completely fused.

Products obtained.—

Weight of metal charged ...	22 lbs. 8 ozs.
,, teemed	16 lbs. 3½ ozs.
Loss ...	6 lbs. 4½ ozs.
Weight of sand charged... ...	15 lbs. 0 ozs.
,, slag, etc., recovered..	20 lbs. 15 ozs.
Gain ...	5 lbs. 15 ozs.

Condition of crucible.—No apparent effect was observed.

Weight of crucible before use ...	31 lbs. 15 ozs.
,, crucible after use ...	28 lbs. 4 ozs.
Loss ...	3 lbs. 11 ozs.

Metal appeared to be non-magnetic.

Materials used.—Dobbs' ferro-manganese, which should have been of following analysis:—

C	6·70 =	558·333	milligram atoms per 100 gms.
Si	0·92 =	32·395	,, ,, ,, ,,
Mn	83·60 =	1520·000	,, ,, ,, ,,
S	0·041 =	1·279	,, ,, ,, ,,
P	0·200 =	6·451	,, ,, ,, ,,
Fe by Difference	8·539 =	152·755	,, ,, ,, ,,
	100·00		

NOTE.—The above corresponds to $Mn_{19}C_7$ EXACTLY, or almost exactly Mn_3C and Fe_3C. The sand would be 99 per cent. SiO_2

Slags.—The slags were for the most part dull grey.

No. 2 trial pot.—New Morgan plumbago pot. 12½ lbs. Dobbs' ferro-manganese, 10½ lbs. cut U bar iron, and 7½ lbs. Calais sand, were placed in pot, which was covered with a clay lid and put into No. 1 furnace at 2.37 p.m. At 4 p.m. the sand began to frit, and by 4-30 p.m. had fritted into a compact sandstone-like mass leaving no loose sand on top, and apparently very little true slag beneath. At 4-45 p.m. the metal was "clear

melted," and at 4-55 p.m. the slaggy or stony mass was pulled off and the metal teemed on to clean floor plates.

Data.—The U bar iron would be of the following composition:—C ·09, Si ·062, Mn ·28?, S ·007, P·014.

Bar iron cleaned.—The bar well cleaned from rust before being used.

Weight of metal charged ...	23 lbs. 0 ozs.
,, teemed	20 lbs. 8 ozs.
Loss ...	2 lbs. 8 ozs.
Weight of sand charged... ...	7 lbs. 8 ozs.
,, slag and stony matter recovered...	10 lbs. 8 ozs.
Gain ...	3 lbs. 0 ozs.

Condition of crucible.—Several cavities were eaten out, but little effect at slag line.

Weight of crucible before use ...	31 lbs. 9½ ozs.
,, after use	28 lbs. 1 oz.
Loss ...	3 lbs. 8½ ozs.

The metal was apparently non-magnetic.

Analysis of products.—

No. 1 Metal		Milligram Atoms per 100 grammes
C	7·9 per cent.	658·333
Si	2·83 ,,	99·648
S	·012 ,,	0·374
P	·180 ,,	5·806
Mn	78·22 ,,	1422·182
Fe	12·63 ,,	225·760
	101·772	

No. 2 Metal		
C	5·89 per cent.	490·833
Si	3·46 ,,	121·831
S	trace	trace
P	0·102 ,,	3·290
Mn	35·65 ,,	648·182
Fe	56·20 ,,	1005·188
	101·302	

Slags	No. 1 A True slag lowest layer	No. 1 B Sandstone second layer	No. 1 C Loose Sand top layer	No. 2 Sandstony Mass
SiO_2	57·92	71·16	82·04	66·70
MnO	27·65	20·29	4·31	24·71
FeO	3·00	trace	(vide Fe)	—
Fe_2O_3	trace	0·78	2·37	0·81
Al_2O_3	0·21	0·62	0·39	0·91
CaO	trace	0·14	0·10	0·08
MgO	0·21	0·45	0·26	0·22
C	2·56	0·56	1·19	0·21
Moisture ...	0·48	0·11	0·52	0·60
Fe (? in FeO)	—	—	1·19	—
Mn (?)	—	—	7·32	—
Total ...	92·03	94·11	99·69	94·04

No. 1 metal.—In order to make quantitative comparisons the figures in respect of No. 1 metal require to be reduced to milligramme atoms per 100 grammes of the ferro-manganese charged, that is to say, that the milligramme atoms per 100 grammes of No. 1 metal to be reduced to 72·083 per cent., the relative weight of No. 1 metal to charge. The figures then become (per 100 grammes of charge):—

	Charge	No. 1 Metal		Difference
C	558·333	474·548	–	83·785
Si	32·395	71·830	+	39·435
Mn	1520·000	1025·761	–	494·239
P	6·451	4·185	–	2·266
S	1·279	0·270	–	1·009
Fe	152·755[1]	162·735[2]	+	9·980[1]

1 By difference 2 By analysis

No. 1 slags.—The different types of the slag were not separately weighed and treated as wholes for analysis, but samples were taken from each to show the composition of each layer. The weight of the whole was 93·056 per cent. on the *charge of ferro-manganese.* It is not therefore feasible to make quantitative calculations, but the analyses are converted into milligramme atoms (per 100 grammes). It must be remembered that if each represented the composition of the whole slag, the figures would have required to be reduced to 93·056 per cent. of what they are for comparison. In the case of 1 C, Fe may have existed as FeO, and Mn not necessarily wholly as metal. Hence ?'s are placed against these figures.

	1 A True slag lowest layer	1 B Stony matter middle layer	1 C Sandy matter top layer
SiO_2	958·940	1178·146	1358·278
MnO ...	389·437	285·775	60·704
FeO	41·725	trace	—
Fe_2O_3 ...	trace	4·881	14·831
Al_2O_3 ...	2·055	6·067	3·816
CaO ...	trace	2·495	1·782
MgO ...	5·203	11·273	6·442
C	213·333	46·667	99·167
H_2O ...	26·698	6·106	28·863
Fe? ...	—	—	21·288
Mn? ...	—	—	133·152

No. 2 metal.—In the table below the theoretical analysis of the charge of bar iron and ferro-manganese is given, and in the next column the milligramme atoms per 100 grammes of charge of each element. In the third column is given the figures for milligramme atoms of elements in No. 2 metal per 100 grammes of charge, *i.e.*, 89·130 per cent. of the figures relating to No. 2 metal (page). In the fourth column the differences are given.

	Charge analysis	Charge gramme atoms	No. 2 Metal gramme atoms	Difference
C	3·6824 per cent.	306·866	437·482 +	130·616
Si	0·5283 ,,	18·602	108·588 +	89·986
Mn	45·5626 ,,	828·411	577·682 −	250·729
P	0·1726 ,,	5·568	2·932 −	2·636
S	0·0255 ,,	0·795	trace −	0·795
Fe	50·0286 ,,	894·906[1]	895·929[2] +	1·023

1 By difference 2 By Analysis

No. 2 slag.—The weight of this stony matter was 45·652 per cent. on the metal charged, whilst the weight of sand charged was 32·609 per cent. on the metal charged. The weight of SiO_2 charged containing 99 per cent. SiO_2 (1639·078 milligramme atoms per 100 grammes) contained 534·482 milligramme atoms SiO_2 per 100 grammes metal charged. The slag analysis converted into milligramme atoms per 100 grammes slag is given in the first column of the table below, and 45·652 per cent. of these figures in the second column. In the third column gains by the slag are set out.

	Milligramme atoms per 100 grammes slag	Milligramme atoms per 100 grammes metal charged	Difference Milligramme atoms per 100 grammes metal charged
SiO_2	1104·304	504·139	− 30·343
Mn	348·028	158·882	+ 158·882
FeO	—	—	—
Fe_2O_3	5·069	2·314	+ ?
Al_2O_3	8·904	4·065	+ ?
CaO	1·426	0·651	+ ?
MgO	5·451	2·488	+ ?
C	17·500	7·989	+ 7·989
N_2O	33·304	15·204	+ 15·204

General observations. Nos. 1 and 2, S and P lowered.—In both cases there was strong desulphurization (as one would expect), presumably MnS being formed and carried into the slag. There was strong dephosphorization as though an analogous phosphide reaction had occurred, and this is interesting and unexpected. It should be noted that this occurred to an extent far beyond being accountable for by portions of metallic charge being held by the slag, or by chance special purity of the materials actually used.

H_2O and occluded gases.—The true slag of No. 1 and the loose sandy matter of No. 1 took up a lot of moisture, and the stony matter formed in Nos. 1 and 2 considerably less. In all cases except the unacted on, or little acted on charge mixture forming "slag" 1 C, the analysis leaves a lot unaccounted for which may have been occluded gases, possibly CO_2, the likelihood of which evidence of other trials favours.

SiO_2, R reactions, Si, Mn, Fe.—In No. 1 there was a gain of 39·435 Si, requiring a loss of 78·870 Mn (or Fe), whilst the loss of Mn alone was 494·239 atoms. In No. 2, where more thorough reaction had occurred, there was a gain of 89·986 Si, requiring a loss of 179·972 Mn (or Fe), whilst there was a loss of Mn alone of 250·729 atoms. In No. 1 the sand charged contained 1092·715 milligramme atoms SiO_2 per 100 grammes metal, and the mean figure per 100 grammes of the slags was 1165 atoms, which reduced by 7 per cent. = 1084 atoms, thus indicating little loss (or gain) of SiO_2 by the slag. In No. 2 the loss of SiO_2 by the "slag" was only 30·343 instead of 89·986, and this, taken in conjunction with the bases and Al_2O_3 in the "slags," indicates (as one would expect) some quite appreciable fluxing of the clay bonding material of the pot. In No. 1 metal there is an apparent gain of Fe, but it must be remembered that the analysis added up to over 101 per cent. and that Fe was only assumed by difference in the case of the ferro-manganese charged. In No. 2 metal the same applies, but the figures confirm each other. The prominent fact in both cases is that the metallic products contained all the Fe charged. No. 1 C sandstony matter apparently held a little very slightly acted on metallic charge. The loss of Mn is astonishing and suggests that it was volatilized (? as carbonyl) to a very appreciable extent. MnO of course would form slag, and also MnS, but even if we assume that Mn_3P remained in the slag or stones formed we have still a big balance to account for. The following calculation furnishes some check, assuming all Si gained to be reduced by Mn from SiO_2.

Mn Losses.

	No. 1 Metal	No. 2 Metal
Reducing SiO_2	78·870	179·972
Forming MnS	1·009	0·795
Forming Mn_3P	6·798	7·908
Balance	407·562	62·954
Total loss	494·239	250·729

Comparing these figures one is struck by the fact that where iron was available as a solvent for manganese the loss was much reduced. Turning to the slags one finds in the case of No. 1 the total Mn content was probably some 329 as a mean, this figure being the mean of the figures for 1A, 1B, 1C reduced by 7 per cent. In No. 2 stone there was only 158·882 Mn or less than that required for the reduction of the SiO_2. It seems quite clear that in No. 1 the Mn loss was mainly due to direct oxidation and partial volatilization, and in No. 2 to reducing SiO_2. No. 1 pot was not visibly eroded whilst No. 2 was, and No. 1 pot lost most weight. Query? Is CO_2 occluded by black pots? Is Mn more easily oxidized when not dissolved in Fe? Does Fe prevent formation of MnCO?

Bases in slags; carbon in slags.—The amount of these confirms the assumption that the SiO_2 fluxed the clay bond of the pots. The only possible sources would be unacted on ferro-manganese and particles of pot wrapped up in slags. I favour the latter surmise. The particles of carbon in the pot are wrapped up in clay, and such clay when fluxed would liberate the carbon particles, which would probably always possess a coating of clay. The large percentage of carbon in No. 1A, the true slag, is very remarkable. Query? Was the carbon found really largely CO_2 occluded by the slag, and given off during the combustion analysis?

Appendix V.

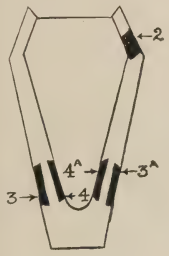
Changes in Composition of Crucibles produced by Melting Steel in them.

Copy extract from the Author's Trials Note Book.

Tests made December, 1909, at Messrs. Sanderson Bros. & Newbould, Ltd., Darnall Works.

An annealed crucible was analysed, and also one from the same batch which had been used three rounds on ordinary high carbon steels. Samples were taken from the interior and exterior of a piece below the slag line, and the full thickness

of a piece from the top of the crucibles, as indicated in sketch. To confirm the absence of Fe_2O_3 shown, two further samples of interior and exterior below slag line were analysed for the state of aggregation of the iron.



	Annealed	Used		
	1	2	3	4
Loss	2·88	·79	1·85	2·62
SiO_2	52·88	52·28	53·66	53·32
Al_2O_3	37·74	40·65	37·67	38·63
Fe_2O_3	3·88	—	—	—
FeO	—	3·96	4·90	3·02
Mn_2O	—	·49	·06	·17
CaO	·32	·31	·28	·27
MgO	·45	·33	·57	·28
	98·15	98·81	98·99	98·31

	3 A	4 A
Fe_2O_3	Nil	Nil
FeO	3·48	3·06

Review.

Conversion of figures into milligramme atoms.—The foregoing figures converted in milligramme atoms per 100 grammes are as under, the loss being calculated alternately as N and CO_2 by way of furnishing probable maxima and minima.

	No. 1	No. 2	No. 3	No. 3 A	No. 4	No. 4 A
Loss { N ...	205·	56·	132·	—	187·	—
Loss { CO_2 ...	65·	18·	42·	—	60·	—
SiO_2	875·50	865·56	888·41	—	882·71	—
Al_2O_3	369·28	397·75	368·59	—	377·99	—
Fe_2O_3	24·28	—	—	nil	—	nil
FeO	—	55·08	68·15	48·71	42·00	42·67
MnO	—	6·90	0·85	—	2·40	—
CaO	5·70	5·52	4·99	—	4·81	—
MgO	11·55	8·17	14·12	—	6·94	—

Loss on ignition enough to account for supersaturation of steel with oxygen.—The first point to note is "loss of ignition."[1] It is significant that soon after such strong heating action as that sustained in melting three rounds of steel the pot should occlude volatile matter. If CO_2 be the gas occluded then the amount contained in the portion of the pot exposed to the molten steel would be enough to supply three or four times the oxygen required to saturate a 50 lb. charge of steel with FeO in solution.

Possible silicates.—In order to study the possible state of the iron oxides the table is reconstructed on a basis of there

[1] The author has since ascertained that a little coke was incorporated in the clay mixture, which somewhat considerably affects the comments given above.

being present bisilicate of alumina and normal silicates of the alkaline earths. The table then would become:—

Position	Annealed No. 1	Top No. 2	Exterior No. 3	No. 3 A	Interior No. 4	No. 4A
Loss (CO_2)	65·	18·	42·	—	60·	—
$(SiO_2)_2Al_2O_3$	369·28	397·75	368·59	—	377·99	—
$SiCaO_3$	5·70	5·52	4·99	—	4·81	—
$SiMgO_3$	11·15	8·17	14·12	—	6·94	—
SiO_2	120·09	56·37	132·14	—	114·98	—
Fe_2O_3 } Fe in { ...	48·56	—	—	—	—	—
FeO } Fe in { ...	—	55·08	68·15	48·71	42·00	42·67
MnO (Mn)	—	6·90	0·85	—	2·40	—

It seems very difficult to account for the pot taking up a lot of manganese at the top, and the figures would confirm what one would expect if Nos. 2 and 4 were exchanged, and I find it difficult to rid my mind of this suspicion. For satisfaction of the equation: $Fe_2O_3 + R = 2FeO + RO$, 24·28 Fe_2O_3 would require formation of 72·84 RO where RO included 48·56 FeO. In No. 2, RO = 61·98, in No. 3, = 69·0, in No. 4, = 44·40. In No. 2 the reducing agents were 6·52 Fe, 6·9 Mn and carbon. In No. 3 the reducing agents were 19·59 Fe and 0·85 Mn and a trace of carbon. In No. 4 the reducing agents were 2·40 Mn and probably CO gas from the steel. In No. 2, the RO silicates were basic, in No. 3, bisilicate, and in No. 4, acid bisilicate. This again is what one would expect if one changed the Nos. 2 and 4.

Appendix VI.

A note on portions of trials made December 1st, 1909, at the Darnall Works of Messrs. Sanderson Bros. & Newbould, Ltd., Sheffield, by the late Mr. S. B. Halcomb and the author.

Inter alia the trials were meant to make comparative tests of the action of ordinary and plumbago crucibles on steel of the same original composition, and of the extent to which Reynolds' slags could protect such steels from the oxidizing action of furnace gases.

Materials used for charges.—In all cases bar steel forged from a Swedish Bessemer ingot, and carefully averaged "tops and bottoms" after cutting up, and of the following mean analysis:—C ·44 per cent., Si ·053 per cent., Mn ·45 per cent., P ·026 per cent., S ·012 per cent., slags ·010 per cent.

Weight of charges.—Exactly 50 lbs. each.

Crucibles used.—For charge E ordinary clay crucible of firm's own make. For charges F,F,F, and G, plumbago crucibles bought from the Morgan Crucible Co., Ltd.

Trial E.—After annealing the new (first round) pot it was transferred to the melting furnace, heated up, and at 1-25 p.m. it was steeled, *i.e.*, charged, and covered by a lid. Charge clear melted at 5-20 p.m., heated up to superheat, but not dead melt, and teemed at 5-35 p.m. Ingot rose slightly in the mould. Analysis of ingot E :—

	C	Si	Mn	P	S	Slags
Ingot	·370	·105	·25	·022	·017	not analysed
Charge ...	·44	·053	·45	·026	·012	·010
Difference ...	−·070	+·052	−·20	−·004	+·005	n.o.

Trial F,F,F.—The intention was to first produce a slag of the composition $3Al_2O_3,5CaO$, and of sufficient depth that lumps of steel charged would be buried therein, no lid being used on the pot, and steel to be charged as fast as each addition was melted down, until the whole charge was melted, and to tentatively maintain heat to see if the "Reynolds'" slag took up RO bases.

NOTE.—In previous trials of a similar nature, where the materials used had contained Fe_2O_3, analysis had shown FeO, and MnO nil. Sufficient experience has been gained to enable their presence to be detected by the appearance and colour of the slags.

The crucible was heated to a bright white heat and charged with powdered slag-forming ingredients at 1·14 p.m. On charging, fumes were given off, causing the dry powder to appear to "boil." The materials charged were 5 lbs. Buxton limestone and 3 lbs. 1½ ozs. of alumina. The limestone was of the following analysis :—

CaO	CO_2	SiO_2	AlFe	Total
Per cent.	Per cent.	Per cent.		
56·60	42·52	0·67	Nil	99·79

The alumina used was supplied as "commercial" (at 1/6 per lb.) by Messrs. Burgoyne, Burbiges, as containing over 98 per cent. Al_2O_3. It yielded on ignition a loss of 3·99 per cent.

The mixture was well fused and some lumps of steel were charged at 4-45 p.m. At intervals further lumps were added, as they could bury themselves in the slag, and by 7-30 p.m. the whole 50 lbs. of steel had been charged and become (together with the slag) "clear" melted. Heat was kept up, or increased until 8-17 p.m., when the ingot F,F,F, was cast. This piped well, and was quite sound. It weighed 50 lbs. 2 ozs. Analysis of ingot :—

	C	Si	Mn	P	S	Slag
Ingot	1·500	·135	·375	·028	·025	n.o.
Charge	·44	·053	·45	·026	·012	·010
Difference ...	+1·060	+·082	−·075	+·002	+·013	n.o.

Trial G.—The plumbago pot was heated to a bright heat and "steeled" at 1-10 p.m. and covered by an ordinary lid. The charge was "clear" melted at 5 p.m., and dead melted (by the ordinary procedure) until 6 p.m., when it was mopped, $\frac{1}{16}$ oz. Al added (as it seemed wild) and teemed. The ingot was sound and weighed 50 lbs. 1 oz. The pot was cut at the slag line. Analysis of ingot:—

	C	Si	Mn	P	S	Slag
Ingot	·850	·410	·400	·026	·015	n.o.
Charge	·44	·053	·45	·026	·012	·010
Difference ...	+·410	+·357	−·050	Nil	+·003	n.o.

Comments.

It will be noticed on comparing trial E with the results given in Appendix III that the loss of manganese in the first round pot used was much greater than in the second round pots,[1] and this confirms the surmises made in the author's comments in Appendix III, which surmises were made previous to this trial E.

In the trials F,F,F, and G, and similar trials of melts in plumbago pots which were not generally pitted, and were merely deeply grooved at the junction level of steel and slag, the volume of the groove in the pot, when carefully measured in all cases, showed by calculation that the carbon lost by grooving of the pot accounted for that taken up by the steel, so much so, that one could almost predict the result of the carbon rise shown by analysis with remarkable accuracy. It directed attention to the cutting of ordinary crucibles, and illustrates the necessity for the warning contained in Appendix A.

In the case of plumbago crucibles the slag *per se* does not cut them. It merely dissolves the exposed surface of clay glaze in which particles of plumbago are wrapped up. The steel merely has a slight neutralizing action on the glaze and does not come into direct reaction with the plumbago particles. Where, however, both react, the basic slag charged, as in F,F,F, or slag formed as in G, dissolves the glaze, exposing carbon, which is dissolved by the steel, in turn exposing the next layer of glaze to the slag, and so on.

The high ratio of Si gain to Mn loss in trial G is explainable thus: Mn reduces SiO_2 to form silico-manganese, but, as much C is present, carbide of manganese and ferrous silicide are formed from manganese silicide and ferrous carbide, and

1 *i.e.* Those used in trial described in Appendix III.

thus the formation of ferrous silicide can take place rapidly. At the same time one would have expected this action to be more marked in F,F,F, except that no RO bases were present in F,F,F slag.

Appendix VII.

Action of Firebrick Ladle Linings on Steel.

Trials made at Blaenavon Steel Works by Mr. T. D. Morgans and Dr. F. Rogers.

On September 21st, 1917, a paper of extreme importance and interest was read by the above-named gentlemen at the meeting of the Iron and Steel Institute, describing a cast of H.E. shell steel made at Blaenavon Works. Also a paper was read by Dr. Rogers on the acid open hearth steel process. The present author subjected both papers to considerable critical analysis, which, *inter alia*, had the, to him, most happy result of creating very friendly relations with those two gentlemen. In the course of his comments he drew attention to the ladle lining having, in his opinion, had a strongly oxidizing effect on the steel.

It must be remembered that the trial was probably made with a view to ascertaining general facts, and not from the point of view of demonstrating ladle action in particular, and it would be of important value if the trial were repeated by those gentlemen with the modifications indicated as required to enable ladle action to be best perceived.

A spoon test was taken (from the nozzle) before casting each ingot, and each ingot was forged or rolled into bars from which seven billets were cut in each case, and, with two exceptions, the top, middle, and bottom billet from each ingot was analysed and investigated.

Inasmuch as carbon and sulphur must be substantially affected by the after treatment of the cast ingot, the value of comparisons between the billet analyses and those of the spoon tests is detrimentally affected. The (present) author would suggest that most information would be yielded from such a trial, by letting the ingots go cold, and then trepanning out cores, say one inch diameter, for purposes of analysis and other investigation. By this means the ingots would not be rendered unuseable for some purpose.

The results were very irregular, most instructively so. In order to render them instructive to ceramists in particular, and

steel makers to the best advantage, the author came to the conclusion that the best method of eliminating the effects of local irregularities, and rendering general chemical changes apparent, was to average the results on a time basis. The charge was 40 tons, and the ingots about 38 cwt. each, and they were cast in eleven pairs from a ladle provided with two casting nozzles. The author therefore averaged the results of each pair, forming eleven time periods, and again, a first and last average of two periods.

The figures thus arrived at by transposing those given in the paper, are set out in Tables A, B and C below, and further rendered clearer by means of the accompanying diagram based on them. It may be noted that Table A relates to spoon test, Table B to middle ingot billets, and Table C to the differences arrived at by subtracting the figures relating to bottom billets from those relating to top billets in each case.

TABLE A.

MILLIGRAMME ATOMS PER 100 GRAMMES.

Means of Ingots No. 8	Pit Samples				
	C	Si	Mn	P	S
1, 2	42·4166	6·1620	15·5909	1·4032	1·9495
1—12 13—22	42·3333 43·4416	6 2001 6 1045	14·9015 14·5000	1·3494 1 3447	1·8775 1·7904
Difference	+1·1083	— 0·0956	— 0·4015	— 0·0047	— 0·0871
Means Differ from Means of 1 and 2	**C**	**Si**	**Mn**	**P**	**S**
3, 4	— 0·5416	— 0·1057	— 1·0000	— 0·0161	— 0 0312
5, 6	— 0·2500	— 0·0715	— 0·3636	— 0·0322	— 0·1248
7, 8	— 0·2083	+ 0·2112	— 1 2727	— 0·0968	— 0 1092
9, 10	+ 1·0416	+ 0·1432	— 0·3181	— 0·0968	— 0 0468
11, 12	— 0·5416	+ 0·0703	— 1·8181	— 0·0806	— 0·1248
13, 14	+ 0·2916	— 0·0353	— 1·2727	— 0·0806	— 0·1248
15, 16	+ 1·5000	— 0·0353	— 0·5909	— 0·0484	— 0·0936
17, 18	+ 1·2500	— 0·2289	— 1·0454	— 0·0322	— 0·0780
19, 20	+ 1·6666	+ 0·0353	— 1·0454	Nil	— 0 2340
21, 22	+ 0·5416	— 0·1233	— 1·5000	— 0·0161	— 0·2651

Table B.

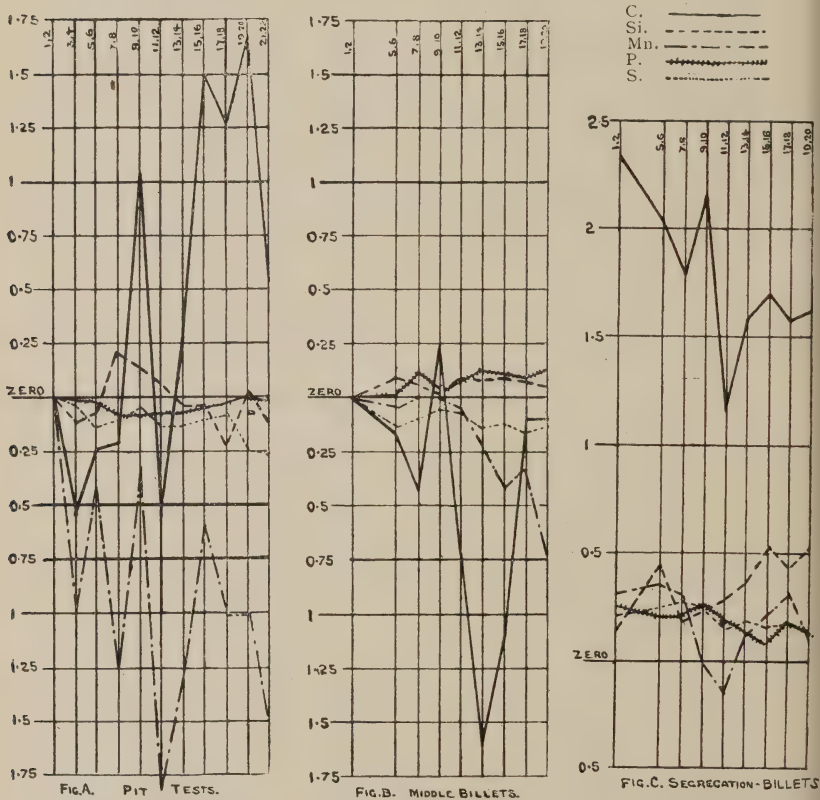
Means of Ingots No. 8	Middle Billets				
	C	Si	Mn	P	S
1, 2	44·1250	6·0211	15·3636	1·2903	1 8091
1, 2, 5—12	43·9083	6·0845	15·3454	1·3484	1 7436
13—20	43·4066	6·1091	14·9318	1·3241	1·6856
Difference	— 0·5016	+ 0·0246	— 0·4136	— 0·0243	— 0·0580
Means Differ from Means of 1 and 2	C	Si	Mn	P	S
5, 6	— 0·1666	+ 0·1057	— 0·0454	+ 0·0161	— 0·1248
7, 8	— 0·4166	+ 0·0705	Nil	+ 0·1290	— 0·0936
9, 10	+ 0 2500	+ 0·0352	Nil	+ 0·0484	— 0·0458
11, 12	— 0·7500	+ 0 1057	— 0·0454	+ 0·0968	— 0·0624
13, 14	— 1·5833	+ 0·0880	— 0·2272	+ 0·1451	— 0·1248
15, 16	— 1 0833	+ 0·1057	— 0·4090	+ 0·1320	— 0·1092
17, 18	— 0·0833	+ 0·0880	— 0·3181	+ 0·1129	— 0 1404
19, 20	— 0·0833	+ 0·0705	— 0 7272	+ 0·1451	— 0·1248
5—12	— 0·2708	+ 0·0793	— 0 0227	+ 0 0751	— 0·0818
13—20	— 0·6843	+ 0·0880	— 0·4204	+ 0·1338	— 0·1248
Difference	— 0·4135	+ 0·0087	— 0·3977	+ 0·0587	— 0·0430

Table C.—Milligramme Atoms per 100 Grammes.

Means of Ingots Nos.	Segregation				
	C	Si	Mn	P	S
1, 2	2·3333	0·1585	0·3181	0·2419	0·2183
5, 6	2·0416	0·4401	0·3636	0·2097	0·2495
7, 8	1·7916	0·1937	0·3181	0·2097	0·2807
9, 10	2·1666	0·2289	Nil	0 2581	0·2651
11, 12	1·1666	0·2816	—0 1363*	0 2097	0·1560
13, 14	1·5833	0·3521	0·1363	0 1613	0·2339
15, 16	1·7083	0·5282	0·2272	0·0806	0 1715
17, 18	1·5833	0 4402	0·3181	0·1935	0·1871
19, 20	1·6250	0 5282	0·0909	0·1613	0·1092
1, 2, 5—12	2·0000	0·2606	0·1727	0·2258	0·2339
13—20	1·6250	0·4622	0·1932	0·1492	0·1779
Difference	—0·3750	+0·2016	+0·0205	—0·0766	—0·0560

*Note.—Inverted Segregation. The occurrence of this inverted segregation is consistent with the (present) author's theory as to the cause of segregation, and constitutes *disproof positive* of the commonly held theory that the main solvent (iron) on crystallising must throw off its solutes.

It appears that only a very small skull, under 56 lbs. weight, was left in the ladle, when emptied. It had only been preheated in the ordinary manner. (In the author's opinion, a very bad and inadequate manner, probably only even visibly heated in local patches. Only one firm, Witkowitz, to his knowledge, attempt to heat their ladles uniformly and highly, which they do easily and cheaply.)



Four or even five reactions may be going on simultaneously in such a ladle, and be exaggerated by its being irregularly preheated These are, oxidation, deoxidation, colloidal segregation, cooling, and definite change of phase (skull formation).

It should be noted that the furnace was tapped, not teemed, and the effect of this on the isotherms in the ladle and temperature gradient of the stream issuing therefrom during casting should be most emphatically borne in mind.

Probably nothing like all the furnace slag was run into the ladle, and it is quite likely that the depth of slag in the ladle would equal that in the furnace. Assuming this to be the case, the slag surface and volume of slag in the ladle would be in the same much diminished ratio as the volume of steel therein to that in the furnace. The ratio of (different) refractory surface acting on the steel in the ladle to that in the furnace would be lessened. The slag would be exposed to cool air instead of very hot oxidizing gases. One would therefore expect very much less catalytic oxidation due to the slag, whilst per contra, the relative affinity for FeO by the slag would be reduced, but in like ratio the surface through which transference would take place. The relative oxidation by the slag to that by the refractory would be less in the ladle than the furnace, but per contra the surplus silica of the ladle lining would be less oxidizing than the free silica of the furnace hearth. In this connection reference to Appendix III is desirable.

Catalytic Bessemerisation in the ladle would be accompanied by falling instead of rising temperature, thus tending somewhat to reverse the Bessemer process sequence, and there would be absence of dilution action occurring in the convertor. The cooler the steel as it enters the mould, the less the later, and the more the earlier, reactions of the Bessemer blow tend to accompany the change of phase, and the more the segregation of iron silicide. In this connection Appendix XVI should be referred to.

When it is remembered that segregation will follow the "Bessemer process rule," and further that the temperature is falling and time protracted, the extremely jerky and irregular mean compositions of the ingots and the colloidal segregation in the ladle become no surprise, but what one should expect. Local eddies could carry down patchy segregations due to the irregular heating of the ladle, and previous irregular action on its glaze formation during the preceding charge.

The swift oxidation at the start owing to the ore-like action of peroxidized ladle glaze is apparent, when sought for. Next comes the "crucible" reaction of siliconization followed by deoxidation. Next comes reoxidation owing to the thickened and more fusible glaze floating to the slag, causing the "crucible" cycle to have to be started afresh. Finally the steel gets so cool that ferrous silicide segregation becomes excessive. All the time the slag would become less acid, but the silicate of iron therein more acid, and greedy enough of base to take up manganese sulphide. Thus there is some desulphurization.

Clearly the steel contained oxygen when tapped, and had oxygen added to it by the ladle lining. It is in no carping

spirit that the author states that steel of such quality in a 100 ton ingot would be valueless for any purpose, and the segregation simply appalling.

When the author first considered this cast, he was inclined to suspect from that, and the results in Appendix V, that occluded or formed carbonaceous gases in the ladle bricks might have affected this Blaenavon steel, and he drew the attention of his friends in the Vickers' firm to this, with the result that they made the investigations, which they have allowed him to publish in Appendix VIII.

Appendix VIII.

On Gases occluded by Firebrick Ladle Linings.

Report *re* results of investigations made at the River Don Works, Sheffield, by Messrs. Vickers, Ltd.

Portions of three bricks crushed and selected of pea-size only and mixed to have an even sample.

1. Analysis of sample:—

OH_2	Nil	per cent.
Loss on ignition...	·20	,,
SiO_2	54·00	,,
Al_2O_3	38·78	,,
Fe_2O_3	5·28	,,
CaO	·30	,,
MgO	Nil	,,
Ak_2O[1]	1·10	,,

2. Extraction in vacuum at a red heat (quantity of gas evolved and its composition) by Sprengel pump:—

One sample, 3 bricks mixed.

Volume at 767 mm. at 15° C. 2·45 cc. contg. 87·7% CO_2 } 150 gms.

2·15 cc. CO_2, 1·44 cc. CO_4 on 100 grms. (pea-size).

One brick, black particles on fracture.

Volume at 751 mm. and 17·5° C. 6·2 cc. containing 78 per cent. CO_2

3·2 cc. CO_2 on 100 grms. (pea-size)

One brick uniform, no black specks.

Volume at 751 mm. and 17·5° C.
2·3 cc. containing 68 per cent. CO_2
1·04 cc. CO_2 on 100 grams. (pea-size).

Remaining gas too small to determine composition.

3. Report of 18th January, 1918.—Gases evolved when ladle bricks are boiled in air-free water, volumes at N.T.P. per 100 grammes.

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1 Ak_2O is contraction for $Na_2O + K_2O$.

	No. 1	No. 3	No. 8 a	No. 8 b	Equal Weights of 1, 3 and 8
CO_2	0·18 cc.	0·23 cc.	0·34 cc.	0·00 cc.	0 34 cc.
O	1·19 ,,	2·04 ,,	1·58 ,,	1·36 ,,	1·62 ,,
N	3·58 ,,	6·26 ,,	4·09 ,,	4·25 ,,	4·14 ,,
Total ..	4·95 ,,	8·53 ,,	6·01 ,,	5·61	6·10 ,,
O in excess of air proportion	0·25 ,,	0·27 ,,	0·51 ,,	0·22	0·51 ,,
Size of bricks	Beans, large	Mixture	Beans, large	Mixture	Particles through ¼″ riddle, and retained on ⅛″ riddle
Condition ..	Freshly broken	Same as freshly broken	Freshly broken	Same as broken, and exposed for 7 days	Freshly broken

Continuing further investigation (No. 2) on larger amount of brick in order to get sufficient gas for a satisfactory analysis of its composition.

4. Determination of CO_2 evolved on ignition in a current of O. Organic matter and CO_2 = ·970 per cent. by weight.

Addendum.

Copy second Laboratory Report, 20th March, 1918.

1. Further experiments on gas extraction at a red heat in vacuum by Sprengel pump. Three lots 400 grammes. From firebrick with black specks on the fracture (pea-size), volume 16·9 cc. at 760 mm. and 18° C.

Consisting of CO_2	31·8	per cent.	by volume
,, O	11·8	,,	,,
,, CO	5·1	,,	,,
Residue	51·3	,,	,,

The residue was incombustible, and, assuming it to be N, its volume almost corresponds to that forming air with the O found.

2. Same as above from firebrick having uniform fracture —200 grammes. Volume 9·6 cc. at 761 mm. and 17° C.

Consisting of	CO_2	63·4	per cent. by volume
,,	O	3·7	,, ,,
,,	CO	10·5	,, ,,
Residue ...	...	22·4	,, ,,

The residue would not explode with O and is probably N. The CO_2 and CO are in the same proportion as above.

Author's Comments.

The temperature at which the gases were extracted would be between 900° and 1,000° C. The analysis of the brick converted becomes as follows:—

Analysis		Milligramme atoms per 100 grammes		Reclassified	
H_2O	Nil		Nil		Nil
Loss on ignition	·20	If H ...	198·4127	If H ...	198·4127
		If C ...	16·6667	If C ...	16·6667
SiO_2	54·00	SiO_2 ...	894·0397	SiO_2 ...	117·8239
Al_2O_3	38·78	Al_2O_3 ...	397·4521	$Si_2Al_2O_7$ ...	758·9042
Fe_3O_2	5·28	Fe_2O_3 ...	33·0413	Fe_2O_3 ...	33·0413
CaO	·30	CaO ...	5·3476	$Si.CaO_3$ ...	5·3476
MgO	Nil	MgO ...	Nil	$Si.MgO_3$ ...	Nil
K_2O	·50[1]	K_2O ...	5·3022	$SiAk_2O_3$ ...	11·9640
Na_2O	·60[1]	Na_2O ...	9·6618		

The author's geological knowledge is nil. The following suggestions are made in the absence of such knowledge. The Fe_2O_3 may have been partly created from actual FeO in the brick by the ignition stage of the analysis, and the clay may have been formed as a bisilicate and oxidized and hydrated in the course of ages. According to this theory the original FeO was 66·0826 mg-atoms. Suppose this were in the form of bisilicate of iron, Si_2FeO_5, the free SiO_2 figure would require to be reduced to 8·7400, or not quite enough to account for bisilicates of the alkalies.

Turning to the "loss on ignition" and the ·970 per cent. (by weight) "organic matter and CO_2" found in the first trials, we observe that ·970 per cent. corresponds to 22·0454 milligramme atoms CO_2 and 53·8410 milligramme atoms H_2O.

If the matter lost on ignition were pure C it would only have created 16·6667 milligramme-atoms CO_2, or much less than the 22·0454 corresponding to ·970 per cent. on weight of brick. If it were H it would have created 99·2063 milligramme atoms H_2O, or nearly double the weight. The author draws therefrom the inference that the loss on ignition is due to hydrocarbons, *i.e.*, vegetable matter.

[1] Assumed total alkalies (determined) being 1·10.

Appendix IX.

Trial roasting of acid open hearth slag made at the Battersea Works of the Morgan Crucible Co., Ltd., Dec. 12th, 1909.

Copy extract from the Author's Trials Note Book.

Object of trial.—This trial was made with the object of testing A. R.'s theory that when acid open hearth furnace slags were in apparent equilibrium with steel, *i.e.*, their composition not changing, the protoxides of Fe and Mn were continually oxidized by the furnace gases, and this oxidation balanced by absorption of oxygen by the steel, or the action of reducing agents therein.

Slag employed.—A fair clean sample of "equilibrium slag" from a large acid open hearth furnace taken before charging finishing additions. The slag was glassy and of an umber colour.

Procedure.—The slag was ground to a fine powder and a magnet passed over it, by which means 0·55 per cent. of magnetic matter was removed. This was obviously not metallic and bluish-black in colour, and all present agreed that it was probably Fe_3O_4.

Treatment decided on.—Fifty grammes of the powdered slag freed from magnetic matter was placed in a shallow platinum dish, and it was decided to heat this for half-an-hour at a temperature of 1,500° C. in a strongly oxidizing atmosphere in a Morgan testing furnace.

Description of furnace.—Morgan's own construction for testing purposes of a size ample for a 30 lbs. brass crucible, heated by bunsen burner using town gas, and capable of burning 600 cubic feet gas and 2,400 cubic feet of air at 10 lbs. per square inch pressure per hour. This furnace is capable of attaining a temperature of 1,600° C.

Pyrometer used. Conduct of trial.—A Féry pyrometer was employed. The dish containing the 50 grammes slag was placed in the furnace, and the gas and air blast turned on. In ten minutes time a temperature of 1,500° was attained. When this had been maintained five minutes an accidental failure of the air blast occurred which took five minutes to remedy, and during this five minutes the temperature fell to 1,380° C. On restarting the temperature very rapidly rose to 1,520° C., and thereafter was maintained hovering just above 1,500° for 25 minutes, when the furnace was shut off. Thus the total time the slag was subjected to at least 1,500° C. temperature was 30 minutes.

Fusing of slag.—At first the slag fused readily, but gradually completely lost its fusibility, and set into a cake, with roughish surface about $\frac{1}{4}$ in. deep. The slag had lost its glassy character, especially near and at its upper surface, and had become much blacker in colour.

Had become magnetic. Increase in weight.—The slag as a whole had become strongly magnetic. Before the whole had quite cooled down the dish and slag were weighed, and, deducting the weight of the dish, it showed that the weight of the slag had become 50·467 grammes, or had increased 0·467 grammes or 0·934 per cent.

Some slag may have been carried away.—It should be noted that the draught of the furnace was very strong, and hence, previous to fusion, it is quite feasible that some of the powdered slag might have been carried away by the furnace gases.

Analyses of slag.—The following analyses were made by Mr. F. W. Harbord:—Ground slag, unburnt, after being freed from magnetic matter, marked *A*. Roasted slag marked *B*.

RAW SLAG *A*.		ROASTED SLAG *B*.	
Fe (total) ...	17·84 per cent.	Fe (total ...	17·26 per cent.
FeO	17·20 ,,	FeO	8·01 ,,
Mn (total) ...	9·37 ,,	Mn (total) ...	9·17 ,,

NOTE.—No satisfactory method of ascertaining the state of oxidation of Mn was arrived at owing to the presence of FeO.

Notes on Foregoing.

Error of analysis.—From a letter received from Mr. Harbord the error as to iron might be ·2, but should be kept within ·1 as a rule.

Bull dog.—Mr. Harbord called attention to the fact that tap cinder from puddling furnaces was roasted to split up ferrous silicates and oxidize them into refractory material, "bull dog," for fettling furnace bottoms.

Growth of slag due to roasting.—The actual growth was 0·934 per cent., but the fall from 17·84 to 17·26 in Fe, and 9·37 to 9·17 in Mn might be due to dilution by a larger amount than 0·934 per cent. O having been taken up, if, previous to oxidation, some slag dust had been carried away, as then the acquired oxygen would be $0{\cdot}934+x$, where x=slag carried away before fusion and roasting. The fall in Fe would, if due to dilution, indicate a growth of 3·36 per cent. in the slag, and the fall in Mn a growth of 2·18 per cent.

Colour of oxides.—FeO, brown; Fe_3O_4, blue-black; Fe_2O_3, red-brown; MnO, dark green; Mn_3O_4, red; MnO_2, dead black.

Oxidation indicated as having occurred.—The intensely magnetic properties of the roasted slag and darkened colour show beyond reasonable doubt that the lessened FeO was due to some FeO being burnt into Fe_3O_4, and in the calculations to follow it will be assumed that the entire fall in FeO was due to this cause. This will not account for the whole of the actual growth of 0·934 per cent., and therefore there was some super-oxidation of manganese.

MnO in silicates should be more roastable than FeO.—When one takes into account the fact that the heat of union of MnO and SiO_2 is 5,400 cals. (per gramme atom), and that of FeO is 9,300 cals., it seems probable that manganous silicate would be more freely roastable than ferrous silicate.

Readjustment of figures.—As before observed, the fall in Fe corresponds to a growth of 3·36 per cent., whilst that of Mn corresponds to a growth of 2·18 per cent. The former figure involves a loss of dust of 2·426 per cent., and the latter of 1·246 per cent.

Proper figures for comparison.—The actual weights should be taken, and, as 50 grammes was the original weight, the figures should be converted into and regarded as demigrammes. In all events then the figures for the roasted slag should be increased by 0·934 per cent., so that the two analyses should read in demigrammes thus:—

	A.	*B.*
Total Fe ...	17·84	17·4212
FeO	17·20	8·0848
Total Mn ...	9·37	9·2556

As the original slag was neither black nor magnetic, and as magnetic matter was separable, we may be justified in calculating that it contained before roasting only Fe_2O_3 in addition to FeO; in any event we can modify the figures as follows:—

	A.	*B.*
Total Fe	17·84	17·4212
Fe in FeO...	13·3735	6·2857
O in FeO	3·8275	1·7991
FeO	17·20	8·0848
Total Mn	9·37	9·2556
O required to form MnO	2·7258	
Total MnO	12·0958	

	A.	*B.*
Fe in form of higher oxide	4·4675	
O required for Fe_2O_3 ...	1·9180	
Fe_2O_3 (?)	6·3855	
Difference in FeO		9·1152
Oxygen required to convert this into Fe_3O_4		0·6761
Oxygen added during roasting		0·934
Do. in forming Fe_3O_4...		0·6761
Difference		0·2579

This amount of oxygen would be required to convert the following amounts of Mn from the form of MnO to the forms stated:—

Mn_3O_4	Mn_2O_3	MnO_2
Mn = 2·6596	1·7731	0·8865

It is thus clear that there was substantial oxidation of manganese protoxide.

Summary.—The difference between the figures for total Fe and Mn before and after roasting is greater than that attributable to errors of analysis by a competent analyst. One must then assume some dust to have been blown away at the outset, that the oxygen taken up was substantially in excess of 0·934 per cent., and further, that owing to loss in the form of dust, the figures in column B should be increased, which would lessen the difference between the FeO figures; in other words, that less than 9·1152 FeO was burnt into Fe_3O_4, and therefore that to a corresponding extent the figure 0·6761 O is in excess of the amount of oxygen consumed in oxidizing FeO into Fe_3O_4.

To enable some estimate to be formed as to the probable conditions the following table has been worked out. First, 0·6761 has been assumed to have been consumed in superoxidizing 9·1152 FeO, and the further amounts shown in superoxidizing 9·37 Mn in the form of 12·0958 MnO to the higher oxides shown as under:—

	Products Fe_3O_4 and		
O Consumed in Peroxidising	(Red) Mn_3O_4	(Brown) Mn_2O_3	(Black) MnO_2
9·1152 FeO ..	0·6761	0·6761	0·6761
12·0958 MnO ..	0·9086	1·3629	2·7258
Total Growth ..	1·5847	2·0390	3·4019

The last figure is little in excess of that required to account for the disparity between the iron figures. The disparity between the total Mn figures would be accounted for by assuming that all the MnO had been oxidized partly into Mn_3O_4 and MnO_2, and the altered colour of the slag would entirely be accounted for on the assumption indicated.

MnO a more powerful catalyst than FeO.—Inasmuch as indications point to four times as much O being taken up by 9·37 Mn as was taken up by 13·3725 Fe it would appear as if MnO were six times as powerful a catalyst as FeO. It may well be that the oxidation of the MnO may have to precede that of the FeO.

Mn harmful in acid open hearth furnace charges.—This conclusion would account for the observed fact that acid open hearth steels made from manganiferous charges are of inferior quality.

Appendix X.

Particulars relating to Trials of "Reynolds" Slags.

Trials made November 3rd, 1909, at the Darnall Works of Messrs. Sanderson Bros. & Newbould, Ltd.

Crucibles used.—Morgan's plumbago.

A.	3 lbs. silver sand ... ... 6 lbs. Buxton limestone ... ... ¼ lb. calcium chloride	Intended to form $CaSiO_3$+a little CaO+a little $CaCl_2$
B.	3 lbs. silver sand ... ... 5½ lbs. Buxton limestone ... ½ lb. anhydrous sodium carbonate	Intended to form $CaSiO_3$+a little Na_2SiO_3+a little CaO
C.	5 lbs. Wragg's firebrick ... ... 4 lbs. Buxton limestone	Intended to form $SiAl_2O_5$+2$CaSiO_3$+trace CaO

NOTE.—The sand was over 98 per cent. SiO_2, the limestone nearly pure $CaCO_3$, and the firebrick of the following composition:—SiO_2, 60·62 per cent.; Al_2O_3, 34·37 per cent.; iron oxide, 3·63 per cent.; CaO, ·65 per cent.; MgO, ·52 per cent.

Slag *A*, at full heat, medium consistency; slag *B*, leathery; slag *C*, watery.

Trials made December 1st, 1909. Crucibles as above.

D,D,D,	75 ozs. Wragg's brick 25 ozs. limestone ... ... 23 ozs. Al_2O_3 (98 per cent. Al_2O_3)	To form $SiCaO_3.2SiAl_2O_5$
E,E,E,	50 ozs. Wragg's brick ... 85 ozs. Al_2O_3	To form $SiAl_4O_8$
F,F,F,	80 ozs. Wragg's brick ... 49½ ozs. Al_2O_3	To form $3Al_2O_3.5CaO$

Slags *D,D,D*, and *F,F,F*, formed easily. *E,E,E*, proved very refractory, as expected, and various acid and alkaline fluxes were added to see how much fluxing would be required.

The total additions made were $CaCl_2$, 12½ ozs.; SiO_2, 40 ozs.; $CaCO_3$, 48 ozs.; Na_2CO_3, 8 ozs. It softened, but did not make a glass.

December 8th, 1909.

A plumbago pot was charged with the following mixture:

H,H,H, 5 lbs. Wragg's brick
3½ lbs. Al_2O_3
3½ lbs. Na_2CO_3

Fume was given off, the bulk of the contents of the pot was much reduced, and a proper slag did not form. Contents of pot emptied into metal pan. It "sizzled" and gave off a yellowish-brown fume

April 20th, 1911.

Slag made from mixture of Wragg's brick, and Steetly magnesian limestone of following analysis:—SiO_2, 2·61 per cent.; Fe_2O_3, Al_2O_3, 2·18 per cent.; CaO, 47·30 per cent.; MgO, 31·01 per cent.; CO_2, 11·54 per cent.; unaccounted, 5·36 per cent. The slag, when made, analysed as under:—

SiO_2	...	...	29·00
Al_2O_3	...	...	16·70
CaO	...	...	19·80
MgO	...	...	22·87
			88·37

Trial of Reynolds' process made April 22nd, 1911, at above works.

Dead melter used.—A special 8 cwt. crude open hearth furnace built for the purpose, and, as little room was available, and capital cost had to be kept down, it had to possess a series of unique features. Town gas was used as fuel, air regenerators only being required, and suction draught was employed. The very hydrogenous gas would have a far more powerful slag roasting effect than ordinary producer gas when complete combustion took place, as was very necessary to secure high temperatures

The hearth was made of magnesite brick, and the middle body of the furnace made to tilt on a hinge for pouring its contents direct into the mould, the charges being too small to employ a casting ladle

The furnace was charged with "wild" steel from white pots, and slag from black pots, and the following is a log of the "dead melt":—

Time Table	Steel					Slag								Remarks
	C	Si	Mn	P	S	SiO_2	Al_2O_3	CaO	MgO	FeO	MnO	P	S	
11-45 a.m.														Furnace charged with steel and slag
12-15 p.m.						21 06	13·64	36 12	21·52	2·16	0·88			Spoon test of slag. Clear, bluish glass
12-17 p.m.														Added ¾lb. SiMn= 0417Si ·0833Mn
12-30 p.m.	·80	·123	·40	·027	·022	25·50	10·09	27·34	33·91	2·13	·72	tr.	09	Spoon tests taken
12-35 p.m.														Added ¾lb. SiMn=·0417Si ·0833Mn. Slight seedy boil
1-5 p.m.	·83	·113	45	·028	·015	29 36	13·82	35·30	18·66	·86	·86			Spoon tests taken
1-30 p.m.	.81	·132	·47	·026	·016	27 94	13·73	31·92	24·84	1·15	·52			,, ,, Bath dead still
1-40 p.m.						29·12	13·14	34·20	22 75	·40	60			Added 1lb. Fe_2 Si=·1666Si. Bath-like mirror
1-50 p m.	·83	·290	·49	·27	·012	27·91	13·72	33·80	20·66	·90	·56	tr.	0·7	Spoon tests taken
1 57 p.m.														Commenced tilting furnace
2-1 p.m.														Ingot cast

The weight of steel charged molten 710—720 lbs. Slag layer about ¾ in. deep.

Ingot piped well and settled well. It should be noted that it was purposely cast fast enough to cause it to be piped in order that if not well deoxidized it should exhibit exaggerated defects of other descriptions, and it was from the first intended to split it for inspection. A little of the steel was unavoidably not drained from the furnace.

Further details regarding the unique ingot, which the author believes to be a world record in regard to low segregation, may be gathered from Journal of the Iron and Steel Institute, page 203, vol. XCVI (last vol.).

Under any ordinary slag in a producer-gas fired furnace heavy falls in carbon, silicon, etc., would have taken place under such a thin film of slag, and the abnormal amount of H_2O in the products of combustion of town gas rendered the tendency to slag roasting very greatly exaggerated. All conditions were the worst conceivable, and in any regular manufacture would be many times more favourable.

Translation of portion of letter, dated May, 28th, 1914, from Messrs. Witkowizer, Bergbau und Eisenhütten, Gewerkschaft, to the author regarding preliminary trials respecting the production of "Reynolds'" slag.

"Five kg. chamotte, 5 kg. burnt dolomite, 7·5 kg. limestone were melted in a plumbago crucible, which mixture yielded a fluid slag of the following composition:—

	Per cent.
SiO_2	28·16
MgO	11·83
Al_2O_3	13·03
S	0·20
FeO	2·26
CaO	44·36
MnO	0·53
P	0·02

In order to test the resistance of a slag of this composition to the action of iron or steel, about 0·7 kg. of steel of about 1 per cent. C was charged into the bottom of a plumbago crucible, and thereabove well mixed, 5·5 kg. chamotte, 5·0 kg. burnt dolomite, 7·5 kg. limestone. The molten slag yielded the following analysis:—

	Per cent.
SiO_2	28·24
MgO	12·39
Al_2O_3	11·68
S	0·12
FeO	2·29
CaO	44·77
MnO	0·53
P	0·025

The slag is therefore inactive with regard to iron.

We wish you to communicate whether this slag is suitable for your purpose, in order, in this event, to undertake the preliminaries for the production of the same in the 6-tons electric furnace. We will give you ample warning to be present, as requested, at these experiments."

Note by the author:—

The amount of steel used in the second trial was not enough to completely remove iron and manganese from the slag. The composition of the slag is shown thus:—

	Per cent.	Milligramme atoms per 100 grammes
SiO_2	28·24	467·5497
Al_2O_3	11·68	114·2857
CaO	44·77	798·0392
MgO	12·39	306·9871
FeO	2·29	31·8637
MnO	0·53	7·4648
P	0·025	0·8605
S	0·12	3·7430

Note ratio $\frac{SiO_2 \text{ and } Al_2O_3}{CaO \text{ and } MgO} = \frac{582}{905}$ $\frac{O \text{ in } SiO_2 \text{ and } Al_2O_3}{O \text{ in } CaO \text{ and } MgO} = \frac{1277}{905}$

In explanation of the foregoing the Reynolds' patent process may be described in a very few words. The refining processes are "rushed," using charges which make them exothermic and yield refined raw steel at high temperature. A separate process in a separate vessel is employed for the finishing process of deoxidation, and added silico-manganese is employed for choice, when the refining vessel is not heated at all if the steel be adequately superheated in the refining process. If not so superheated the steel must be charged into a suitable furnace, preferably nearly neutral lined but *not acid*. It may be an ordinary basic furnace, and the conditions are so arranged that it can overcome its radiation losses and admit of nascent silico-manganese effecting reduction.

The slag and lining must be absolutely stable. This involves absolute or nearly absolute freedom from iron or manganese silicates. The slag must be composed of non-oxidizable oxides solely. It must be composed of the elements Si, Al, Ca, Mg and O, and must not be acid. It must be fusible. Then a layer only, say 1 in. to 2 in. thickness will shield the steel from oxidation. Where no furnace is required the vessel may be basic (which, however, is risky, owing to bases not remaining caustic), but preferably the lining should be nearly neutral, and one of the problems to be solved is the production of true $SiAl_2O_5$ + trace Al_2O_3, or $SiMgO_3$, which would be refractory enough if rendered basic enough.

It should be possible to free MgO from Fe and Mn oxides and the alkalies by a wet process, and mix the product with pure quartzite and produce the ideal article.

After refinement, and before deoxidizing, every trace of the refining slag must be removed from the steel.

The author alluded in the paper to the trials arranged for at Witkowitz when the war broke out.

As arranged at Witkowitz the 200-ton Talbot furnace was to be used as the refining furnace. A 70-ton (well superheated) basic furnace to receive the raw steel and finishing additions, and "Reynolds'" slag from a 70-ton ladle, in which they would be assembled, and the 6-ton electric furnace was going to be used for producing the iron-free slag. 70-ton ingots (for guns) were to be cast, trepanned, and the trepanned pieces split axially and thoroughly investigated.

Having schemed to meet the case without any heating of the "finishing" process vessel, except preheating it, the problem is quite altered and the author has grounds for hoping to get it tried.

Appendix XI.

Abstract from the author's British patent No. 111,355.

"Improvements in the manufacture of refractory bricks or the like for furnaces or the like."

Refractory bricks for furnaces and refractory furnace adjuncts such as nozzles and stoppers suffer considerable destruction in the furnace until they have become heated to a sufficiently high temperature to "season" them.

Whether the refractory material is acid, such as quartz powder, basic, such as caustic magnesia, or neutral, such as fireclay mixed with alumina to correspond with the formula Al_2SiO_5, some chemical or physical change or both must be brought about by heat in the mass before coherence sufficient to withstand thermal expansion and attrition, increased refractoriness and resistance to chemical erosion are attained. No doubt this change is the "seasoning" which the bricks or the like undergo in the furnace, but not earlier, because raising a mass of them to the necessary high temperature in a kiln would be preceded by their collapse.

It has been proposed to season the brick or other article as a whole by heating to a very high temperature in the course of its manufacture, but it is difficult and costly to raise the temperature of the mass to so high a degree, and in particular to avoid the deformation which accompanies the incipient fusion that should occur if the seasoning is to be effective.

My invention consists in heating the working surface of the brick or the like to such a temperature that the changes which impart coherence to the article in use, and the formation of compounds of the constituents of the mixture, occur to a greater or less depth in the surface before the article is brought into use. I bring about this superficial change sufficiently to enable the brick or the like to resist the disintegrating influences in the furnace until by penetration of heat ample seasoning has been effected.

To illustrate my invention I will describe it more particularly with relation to bricks, nozzles or stoppers made of such materials in such proportion that the ratio of silica to alumina therein corresponds with the formula $SiAl_2O_5$, or with a proportion of alumina very slightly in excess of this, so that the product is slightly basic. The moulded article is burnt in a kiln in the usual manner and then subjected to my invention, that is to say, the working surface is heated to such a temperature that the acid constituent becomes melted or incipiently melted and combines with the basic constituent to form a most highly infusible glazed surface of adequate depth. The mode of operation depends on the working surface, that is to say, on what portions of the surface are subject to heat and attrition when the article is first exposed *in situ* in the furnace or the like. When the brick has been made of a mixture of a good fireclay and a pure form of alumina, the temperature required to produce incipient fusion is usually in the neighbourhood of 1,700° to 1,750° C. according to the composition of the fireclay, whilst the product of reaction melts in the neighbourhood of 1,850° C. or higher.

Taking, for example, bricks to be used as headers or stretchers in the walls or roof of a furnace, it is only necessary to form the said refractory glaze on one end or edge of the burnt brick, whilst for regenerator bricks all the surfaces will have to be treated by heating each surface one at a time.

The bricks are bedded in the floor of a furnace, the working surface uppermost, the spaces between them being filled with a ramming of highly refractory material which will not chemically react on them, such as chromite, plumbago, or ground carbon and tar, say fine coke and tar. The furnace is then heated to the required temperature, when the desired superficial change occurs in the bricks without destruction owing to their position and the absence of any serious attrition.

In the case of a steel foundry ladle, nozzle, or stopper, it is necessary to employ special devices in order to prevent the falling away of the incipiently fused surface, previous to

seasoning, and restored and increased refractoriness being secured.

In the case of a ladle nozzle, one of very numerous means of achieving this is the following:—

A revolving drum gas furnace is employed. In one end wall of this the nozzle to be treated is embedded similarly to the manner in which it will be embedded in the casting ladle in which it is to be used. The furnace may be conveniently primarily lined with plumbago, and the end opposite to the nozzle is made detachable. An inner lining is made of a ramming of fine quality coke and a little tar or gum, as a binding agent. Lumps of coke are introduced into the furnace and the detachable end wall is attached, such end wall having a tuyere hole through its axis for the introduction of a tuyere. A bunsen burner is introduced into the hole, having first ignited the gas jet, and an excess of air is blown in, with the gas. As soon as ignition of the coke is thorough, the gas may be shut off. The furnace is rotated at such speed that the incipiently fused surfaces have not time to fall away. The nozzle itself forms in this case the outlet for the furnace gases.

NOTE.—Endless ringing of the changes is rendered possible by means of this invention. For example, kaolin-alumina arch bricks for melting furnace roofs might be made tapering in composition a little in proportion to the temperature gradient, only the heated end being of neutral mixture, and treated, whilst the end exposed to the atmosphere might be simple fireclay.

Just as in teeth enamel is formed interiorly as they are worn away exteriorly, so would worn working surface be replaced below the surface, in the interior of the brick.

In the case of ladle nozzles it is not lack of refractoriness in kaolins which gives rise to the wear, but the reduction of SiO_2 by Mn mainly, and in less degree by Fe. Mere admixture with alumina would hinder, not prevent action on the kaolin constituent, whilst the combination of kaolin with alumina forming monosilicate of alumina would prevent the attack on the silicic acid.

Bricks made of such mixture possess very valuable properties. They may be flung damp even into steel-melting furnaces, heated to a white heat, raked out roughly, falling say 30 inches on to the charging platform, picked up by tongs and one half the length chilled off in water. The author has frequently subjected them to this treatment, and, holding the chilled end in the hand, lit a cigarette with the hot end.

But in crucible furnaces they failed at firebrick temperatures, only the remainder standing great heat. When a reserve

of sudden temperature raising capacity exists, and one can persuade the furnaceman to go contrary to his instincts and experience, and the moment they show signs of failure, quickly raise, and then drop the temperature, one may sometimes dodge rendering them very refractory before they collapse.

Appendix XII.

Examples of Unexpected Catalytic Action.

In his quest for the evolution of a dead melting process and conditions the author turned in 1903 with great hopes to the possibilities of electric furnaces of a suitable type being evolved.

The induction furnace is fundamentally bad, in that the slag is cooler than and heated by the metal, and the bath of most objectionable form, with a large surface to volume ratio.

The semi-arc furnace is of good form, but the intense local, and bad general heating conditions, favour unknown chemical conditions, and probable nitrogenation of the steel.

Neither type, then, satisfying requirements, he sought to evolve a suitable type, in which buried heating resistances, or immersed enclosed arc elements were used, to more evenly heat the bath of molten steel charged, which merely required to be slightly superheated, or merely its heat maintained.

He soon found, though, that it was far more difficult to to find refractories to stand absence of, rather than presence of, oxidizing atmospheres.

These difficulties proved to be of so insuperable a nature that he abandoned the attempt and turned to modifications of the open hearth gas furnace and processes as the best direction in which to seek to evolve a good process. Thus he now only looks to the electric furnace as an auxiliary in which to melt very oxidizable alloy additions to modified open hearth steel.

Some experiences of his own and of his friends with regard to catalytic and other unanticipated reactions concerning refractories, which render them volatile in the presence of reducing conditions, at many hundred degrees lower temperatures than they even soften at, in the presence of oxidizing influences will, he thinks, interest, and in some cases possibly surprise some members of this Society. They serve to show that one should always look out for the catalytic power of the alkalies.

Two great firms, friends of the author, one British and one Austrian, very naturally tried the apparently ideal form

of gas producer, viz.: a big blast furnace type producer, air blasted, from which the scoriæ were tapped out molten, and, lime fluxes being used, there was a tendency to lower the sulphur content of the gas. In both cases the experience was similar, although very dissimilar coals were used. The gas burnt in the furnace with a dust-laden look. After a very few weeks' working it became evident that the gas flues were choked. They were choked some distance from the producer (where cooler) by a very tenaceous light feathery purple-grey deposit. The author has been allowed to give an analysis made of one of these deposits. It is as under:—

	Per cent.	Milligramme atoms per 100 grammes
SiO_2	63·6	1052·98
Al_2O_3	7·6	74·36
Fe_2O_3	5·59	34·98
MnO	4·66	65·63
CaO	1·47	26·20
MgO	1·07	26·51
P	0·43	13·87
S	2·87	89·52
K_2O	3·93	41·67
Na_2O	8·72	140·42
	99·94	

As to whether the gas possessed a peculiar "electric furnace" stench is not known to the author. He alludes to this, as this has accompanied most of the most surprising phenomena to be described, and he wishes this to be borne in mind in considering the above.

All appearances point to this deposit being due to condensation of volatilized matter. Possibly hitherto unknown carbonyls have been formed, doubtless catalytic actions have predominated, and also some reactions have been actually reciprocated, with falling temperature of the gas.

During the author's experiments with electrical resistances where carbon and highly refractory oxides were brought into contact, and the atmosphere to which they were exposed was reducing, the refractories volatilized, often at not at all high temperatures, and the fumes given off possessed an appalling stench, something like that of burning india-rubber, but very pungent. They acted in a most extraordinary manner on the mucous membranes. One effect was, that on passing the finger lightly over the tongue, blood would squirt out from every pore thereof. It was feasible to collect small amounts by means of "sooting" a clean plate held in the fume. Regardless of whether the refractory materials were acid or basic, the HF test

showed the deposit to contain about 65 per cent. silica. It was generally greyish-brown. It proved to contain a considerable percentage of carbon. The fume burnt with dusty brown flame. Alumina and other high refractories were found in the "soot."

Now this sooty deposit was so light that several square feet area were not weighty enough for proper complete analyses to be made. It was so strong that pieces the size of a large postage stamp could be held, like one, by the corner. It was these experiments resulting in this experience which caused the author to abandon, as hopeless, the evolution of a metallurgically unobjectionable form of electric furnace. The chief types of resistances employed were as follows:—

(*a*) Carbon mixed with refractories and moulded.

(*b*) Loose carbon, also mixed with powdered refractories.

(*c*) Granulated carbon mixtures (first moulded).

(*d*) Enclosed arc elements, the positive pole being of crucible form, and the negative a carbon rod.

In the case of the enclosed arc, plumbago enclosing elements were employed for one pole, and an Acheson graphite rod for the other. These were insulated by means of a collar of material, which, on analysis, appeared to be monosilicate of alumina, very low in alkali.

Doubtless, from various evidence, it was a mere mixture of high-class kaolin, and some pure form of alumina. In this case, by radiation from the arc and contact with the gases it enclosed, it was exposed to very high temperatures; but it should be noted that it was not *fused*, it was *vapourized*. The elements were immersed in the charge to be heated.

In consequence, some small crucibles were obtained, 2 in. high, and 1 in. internal diameter, and only ⅛ in. thickness. Some of these were made of the (apparent) monosilicate mixture just mentioned, and some of magnesite. Several of each type were nearly buried in a loose carbon resistance furnace. They were charged with fine steel turnings, which would be freely fused at 1,450° C. about. They were slowly raised in temperature, no attempt being made to rapidly force heat through their walls. All, save one of the magnesite ones, fumed away before the charges were molten, and left little more than their top rings. The odd magnesite one withstood three meltings of its contents before it failed. This shows that one must not attribute the failure so much to minute arcs, playing for limited periods on the small pot walls, but to the action of some catalysts, from which, by some fluke, the one magnesite crucible was specially free.

The author thinks that reduced elements and compounds, mixed with CO gas, compose the fume at high temperatures, and, that if ignited, the original refractories and carbonic anhydride are reproduced, but that when cooled in the absence of oxygen the reduced products reduce carbon monoxide, thus not only reproducing the original refractories but the solid carbon.

Neither could time be spared, nor the 300 horse-power electric apparatus for further abstract trials, which obviously would not forward the ultimate object sought after, a better steel process.

Electric steel-making furnace roofs do not wear correspondingly well to those of gas furnaces, and some strong hint as to this is furnished by the foregoing. Again, the local arcing volatilizes some Fe and Mn, which will form protoxide fluxes for silica roofs. In gas furnaces iron vapours attack the silica bricks in like manner, but the protoxides are roasted into magnetic oxide, and literally, if anything improve the refractive qualities of and "season" the bricks. In the case of the gas regenerative portion of the furnace though, during the FeO formation period, the bricks are fluxed and deformed. Further, the author has known them increase in weight up to some 30 per cent. in some six weeks.

Appendix XIII.

Examples of Abnormal Segregation.

On reference to Appendix X and Journal of the Iron and Steel Institute, vol. XCVI (last vol.), page 203, it will be seen that the author claims to have produced by his process an ingot constituting a record in regard to absence of segregation. He also claims to have produced the opposite record, the greatest known segregation. This is so instructive as to be germane to the matter now under consideration.

At the beginning of the present century such well-founded rumours were in circulation as to steel being able to be dephosphorized and desulphurized by the action of hydrogen, or hydrocarbons, that the author sought and obtained opportunities to make unique trials to test the action of pure hydrogen, town gas, water gas, and petroleum on molten steel. These gave most unexpected results, which proved the rumours to be "wild" from the practical point of view, but not void of some real basis.

The presumed elimination of the metalloids was in the form of PH_3 and SH_2. The most complete trial of the series was one made at the Barrow works of Messrs. Vickers, Ltd., in 1902, which they have been good enough to allow the author to publish.

A 30-cwt. charge of foundry pig-iron was blown five minutes in a Tropenas convertor. Roll sulphur, in weight ·16 per cent. of the charge, was placed in the ladle and the charge teemed on to it, and was well stirred and then returned to the convertor, and blowing completed in the ordinary manner. For some reason the charge "blew wild." The steel was evidently more oxidized than usual. The blown down soft steel was teemed into the ladle, and the petroleum vapour was blown into it.

The arrangement for doing this consisted of a powerful hand-pump, which pumped oil from a barrel through a long copper coil, heated in a coke-fired furnace, which easily vapourized it as fast as pumped. The coil was in turn connected with a refractory covered tuyere, which was dipped deeply into the contents of the ladle.

The petroleum vapour produced such violent ebullition in the ladle that splashings of steel were ejected from it to a considerable amount, and the steel was rapidly chilled, so much so, that only a portion of the contents of the ladle were able to be teemed from it, and a substantial skull was left behind.

Exact quantitative calculations cannot be made, for the difficulties of the trial prevented, for example, proper recording of the amount of petroleum pumped into the steel.

The following analyses show the astounding segregation actions which took place, and which included negative manganese segregation:—

	C	Si	Mn	P	S
Foundry Pig from Cupola ..	3·60	2·0	0·71	0·367	0 078
Sulphurised Steel after blowing ..	0·11	0·05	0·18	0 479	0 060
Steel teemed from ladle ..				0 161	0 65
	0·64	0·14	0·11	0·133	0·704
Steel splashed from ladle ..	0·17	0·07	0·10	0·45	0·068
	0·16	0·15	0·08	0·482	0 075
Steel skulled in ladle	0·31	0·07	0·13	0·045	0·063
	0·30	0·075	0·12	0·05	0 06

Transmuted into milligramme atoms per 100 grammes, and rearranged, taking the means of dual analyses, the above results become as under:—

	C	Si	Mn	P	S
Cupola Pig	300·0000	70·4225	12·9090	11·8387	2·4329
Blown Steel	9·1666	1·7606	3·2727	15·4516	1·8715
Teemings	53·3333	4·9296	2·0000	4·7419	21·1167
Splashings	13·7500	3·8732	1·6363	15·0323	2·2252
Skull	25·4166	2·5528	2·2727	1·5323	1·9183
Blown Steel	9·16	1·7606	3·27	15·4516	1·8715
Teemings	53·33	4·9296	2·00	4·7419	21·1167
Difference	+44·16	+3·1690	—1·27	—10·7097	+19·2452
Blown Steel	9·16	1·7606	3·27	15·4516	1·8715
Splashings	13·75	3·8732	1·63	15·0323	2·2252
Difference	+ 4·59	+2·1126	—1·63	— 0·4193	+0·3537
Blown Steel	9·166	1·7606	3·27	15·4516	1·8715
Skull	25·416	2·5528	2·27	1·5323	1·9183
Difference	+16·250	+0·7922	—1·00	—13·9193	+0·0468
Teemings	53·333	4·9296	2·0000	4·7419	21·1167
Skull	25·416	2·5528	2·2727	1·5323	1·9183
"Segregation" ..	27·916	2·3768	—0·2727	3·2096	19·1984

Now the belchings from the ladle were of course the smallest portion of the three portions the charge divided itself into. They were "mechanically" ejected, and least exposed thereby to chemical reaction of any kind. They show this.

Carbonization was to be expected of course in all cases.

There was an undoubted gain of silicon and loss of manganese due to manganese reducing silica from the slag or ladle lining evidently.

There was a very heavy general dephosphorization and undoubted heavy resulphurization. This the author surmises to be due to the ultimate reaction $Fe + MnS = FeS + Mn$, for in spite of addition of 200 per cent. sulphur to that in the cupola iron the blown steel contained less, and the author presumes that the steel was desulphurized according to the equation $FeS + Mn = MnS + Fe$ in the convertor. Also segregation may have falsified the tests taken from the steel.

There is evidence that segregation falsified the corresponding phosphorus test in the opposite direction. The "negative segregation" of Mn should be noted, and the enormous sulphur segregation.

Appendix XIV.

The Necessary Conditions when Casting Steel.

For casting to shape it is essential to provide a well-heated mould formed of such a bad conductor of heat, and of such thickness as to be incapable of radiating heat from its exterior as rapidly as it is conducted within the mass of molten or solid steel; in other words, so that isothermal lines do not exist within the body of the main steel casting, which then would, when completely solidified, be of the exact volume, and just fit the interior of the mould without putting pressure on it, except at the bottom. A largish feeding head should be provided, and to avoid isothermal lines, the mould should be completely filled *as fast as possible.* The feeding head should be kept hot. The steel should be covered therein by a non-catalytic slag, to shield it from oxygen and nitrogen, and be kept hot by means of the electric arc, or other suitable device, until the casting main body has solidified.

Ingots for forging must be treated in the like, or exactly opposite manner. The opposite manner is that adopted, viz.: casting them in chill moulds. The rate of absorption of heat by, and radiation or convection of heat from, the mould body is made as high as possible. It should be noted that metallic substances decrease in conductivity of heat with rise of temperature, and compounds increase with rise of temperature, especially basic ones.

If a cylindrical chill mould were filled suddenly, the isotherms would be cylinders also, and the resulting ingot would be a tube. That tube, however, would be under heavy pressure at the bottom during its formation, and as a solidified elemental shell formed, owing to steel being, of course, not the impossible perfect conductor of heat, it would be burst by the infinitely intense tension to which it was subjected by the hydrostatic pressure of the colloidal steel enclosed by it, as, during cooling, it contracted and lost the support of the mould. The mould, too, must have a bottom, and that a chill one also. This would have the effect of tending to cause the cavity to take the form of the solid of revolution of a rectangular hyperbola round its asymptote. To keep free from conditions which burst the solidifying shell we must fill the mould slowly, descensionally, and absolutely axially, at such a speed that the isotherms take approximately the form of the solid of revolution of a hyperbola with its vertex downwards, for the mould is rising in temperature all the time. Could it be kept cool, say, by water jacketting, then the isotherms should be parabolic. As the isotherms must be hyperbolic, the mould must be in the form of an

inverted frustum of a cone. It must be provided with a head piece of the type suited for a casting, and, if this could be perfect, the result would be an ingot with a flattish cupped top, the bottom of such cup being level with the top of the chill mould.

As a compromise, this head box was made of smaller diameter than the mould, and cavities confined within it as far as possible. The compromise consists in a main piping in the head, of the form of the hyperbola referred to its asymptote, and the hyperbola referred to its axis, the portion between the two isotherms being irregular sponge.

The requisite paramount condition must be uniformity of temperature of the stream entering the mould, and this could only be achieved by means of electrically maintaining its temperature constant, using the stream as the resistance for a variable low tension current. Some compensation is furnished by casting the slower, the hotter the steel. There is a proper temperature, and this should never be exceeded, or fail to be attained. As the temperature gradient of the steel is a function of time, temperature and cooling surface of the ladle, it is worse for a given speed of casting, the larger the charge in the ladle. For this reason the best large ingots tend to be produced from a multiplicity of charges tapped in proper succession. It is more troublesome and costly. It is for this reason, that the larger the ingots made, the smaller the melting furnaces employed. The larger the ingot, the smaller the relative speed of casting it, and *the larger the ratio surface ÷ volume of stream from casting vessel, to the solid portion of ingot, thus the greater need for excluding the subjection of the stream to the pneumatic process of oxidation.* The larger the ingot, and the larger the charges used for large or small ingots, the more *conditions obtain, which are inverse of what they should be, in ordinary, up-to-date works practice.* The larger the ingot, the greater the segregation.

This is by no means the end of a most serious indictment. Ascensional casting must produce an ingot piped from top to bottom. Each ingot *must be cast descensionally, and with an absolutely axial stream.* The chill portion of the mould must be polygonal, and formed of arcs produced by reversing the arcs of the circle enclosing the polygon, so as to increase the surface chilling effect of the mould, and provide for the most delicate portions of the skin being in compression.

The hexagon is the natural form, but the octagon that most used. When a series of ingots is cast from one ladle full, the temperature of the steel is falling all the time, and, with a fixed sized nozzle in the ladle, the speed gradient falls

rapidly owing to increasingly colloidal condition of the steel, and falling hydrostatic pressure. The steel must be run full bore, or nearly so through the nozzle, otherwise it cannot be compact and axial. One cannot expect to obtain variable nozzles from ceramists, when locomotive engineers cannot evolve a perfect variable nozzle for the blast pipe of their locomotives. Thus the first ingot is cast too hot and fast, the last too cool and slowly. The first is over-piped, the last under-piped or honeycombed. To lessen these evils, small tundishes are often employed. These are acid, and the splashing of the stream and other attributes increase the detrimental effects of pneumatic oxidation. The "crucible" reaction on the acid nozzles and stoppers results in erosion of them, and thus slags due to this and the pneumatic process are carried by the stream *and beaten into the freezing portions of the ingot.* Under any other conditions they would merely float up.

Yet one more ghastly condition obtains. The fluxed surfaces of the acid nozzle and stopper readily weld. If the "plug runner" closes the valve safely he can never open it again. He has to exercise great skill *at the risk of his own and his fellow workmens' lives.* During transit of the ladle from mould to mould, he opens the valve momentarily at frequent intervals, to obviate welding of the valve and its seating.

In consequence, the "cheap and nasty" steel maker uses nozzles of such bad quality, that their erosion provides requisite variation of aperture to some approximate extent.

The following words are strong, but, the author contends, not too strong. He regarded it as a disgrace to himself as a Briton, and a man purporting to be a metallurgical engineer, not to be able to scheme some simple means of overcoming the defects, which have produced many a real fatal tragedy. One invention is indicated in Appendix XI. The other invention he has lodged a complete specification for, but, at the moment of writing, the patent has not yet been granted. Before describing this invention, he may say that he insists on neutral nozzles, in lieu of basic, for the bases do not remain caustic, and readily decrepitate. Such decrepitated matter is perhaps worse even than bits of slag in an ingot.

The new invention broadly consists of eliminating the necessity of valve devices when casting, all ingots being cast from one ladleful almost simultaneously, at the proper mean speed, and with a very flat speed, as well as temperature gradient. It is founded on employing *suitable* tundishes placed over each mould. These tundishes are of special form. They have a main body *comparable* in content capacity to that of the chill

mould, and, integral with the main body of the tundish, is a long depending spout. The content capacity of this spout is comparable with that of the ingot feeding head box. At the bottom of the spout is fixed a nozzle of the required aperture. (Of course suitable refractory linings are provided and well preheated.) The spout is made *pro tem.* integral with the mould by means of a suitable, say, conical connection. A branch, closed by means of a framed lens of glass or mica, is provided as a "peep-hole," and an ample branch is provided with a sensitive non-return valve, to relieve pressure due to heated gases. The long spout serves the purpose of flattening the hydrostatic pressure gradient during emptying of the tundish. It remains, then, to define the meaning of the word "comparable." When casting the first tundish body must not be emptied before the last is filled. It must possess a margin of capacity to allow for wave and splash actions.

The tundishes are provided with covers, and these, in turn, in the case of large ones, with peep-hole branches and filling neck, the latter, in turn, being provided with a coverlid. The casting ladle is provided with a slag dam, and very quickly and safely operated teeming gearing. The tundishes are filled with steel up to a mark, at some twenty to forty times the rate of their discharge. If the plurality of ingots be under six, or thereabouts, their capacity may be less than that of the mould, but, if the plurality of ingots be great, then they must be able to be filled with the entire charge required for the ingot. If the ingot be of greater weight than the capacity of the ladle then the tundish must be of a capacity equal to that of the ladle, which, when emptied, will be in perfect condition for and be used for receiving the next charge. Thus the temperature-time gradient is maintained as flat as possible, and plug troubles eliminated.

The author is certainly no authority in commercial matters, nevertheless, he fearlessly follows his late father's dictum, that the best and most conscientious manufacturing process is always evolvable into the cheapest, and commands the highest selling price, in other words, yields the greatest profit. This, in turn, is expressed by the old adage, "Honesty is the best policy." The author feels sure that with very little aid from one of our great steel-making, and also a great ceramic firm, he can evolve neutral-basic steel cheaper than the cheapest basic, and far superior to the best acid which it is possible to make.

Appendix XV.

The Paramount Influence of Silico-manganese as shown by the Acid Bessemer Process.

As stated in the paper, the course of the acid Bessemer "blow" is Nature's best text book, not only as to the proper sequence of the stages of producing refined steel from pig-iron (the first process of treating the ore being always the production of pig-iron), but as to relative ignition temperatures of reactions, that is to say, the temperature sequence.

The speed of the blow with a given pig-iron, at a given temperature, decides the temperature gradient of the process, and, therefore, the slower the "blow" the more the pig-iron must be one to yield exothermic reaction with the FeO produced during the "blow." When the periods do not overlap it means that the temperature of non-reaction, the first reaction, is too low for that of inception of the next. When they overlap, it means that the temperature of non-association of the first is above that of ignition of the second, and so on.

The results of different speeds of blowing, and use of different pig-irons, can be predicted from what has been stated in conjunction with the crude calculations given, and the only amendment apparently needed thereto is that the temperature of non-association of exothermic iron silicate formation is not much above, but about the same as that of ignition of iron-carbide and FeO reaction. In making statements in prediction form for brevity's sake the author begs to state that they are confirmed by all the data he has collected and reduced to diagrams. Practices may be broadly classified as under:—

1. *British.*—Slow "blow" (about 15 to 20 minutes), shallow bath, low pressure air blast. Ferro-siliceous iron used. Periods two, overlapping: (*a*) Slag formation. (*b*) Decarbonisation.

2. *American.* Rapid "blow" about 9 minutes), deep bath, high pressure air blast. Ferro-siliceous iron used, but about only half as siliceous as British. Periods similar. If pig-iron is too hot to start with, a third overlapping period of resiliconization occurs. The author has been informed of as much as 0·6 per cent. silicon being reduced back.

3. *Witkowitz.*—Old convertors of British type. The iron of unusual type Ferro-siliceous, mangano-siliceous, and mangano-carbonaceous. From outset rapidly increasing carbon loss. Crossing this, and almost independent thereof, three slag periods: (*a*) Formation of double silicate of iron and manganese. (*b*) Reduction of silicate of iron *in toto* by silico-manganese;

that is to say, stationary silicon in steel and lessened iron in slag. (*c*) Loss of silico-manganese; that is to say, formation and oxidation of nascent silico-manganese and iron carbide from carbide of manganese and iron silicide; towards the end heavy colloidal phosphorus segregation.

When the old convertors were replaced by the American high pressure blast, rapidly blown type, the process was similar, but the steel could be raised to extremely high temperature without the resiliconization accompanying a non-manganiferous charge. The temperature could be raised so high as to admit of adding considerable quantities of cold scrap to the charges from time to time, even to a total of 30 per cent. scrap. The high temperature lessened the phosphorous segregation. At very high temperature the gases looked like and smelt like nitric acid fumes.

4. *Swedish Bessemer.*—Very slow blown in fixed convertor. Highly manganiferous iron, mostly carbide. Two non-overlapping periods: (*a*) Direct formation of silicate of manganese, no carbon reaction. (*b*) Oxidation of nascent silico-manganese and iron carbide and manganese-carbide direct; that is to say, formation of manganese silicate by union of MnO with the silica lining of the vessel, and additional formation of silico-manganese by attack of manganese carbide on the vessel lining, and oxidation thereof. In the result the steel is kept low in FeO all the time, and is tapped when the carbon has fallen to the desired level. The slag, being not very acid, and unable to get any other base to satisfy it, takes up manganese sulphide. Thus low sulphur steels are made. The rapid blown processes are, of course, most economical in pig-iron. The British practice is the worst, for neither slag formation nor carbonaceous anhydride formation is at the best point of temperature. Heavy iron losses occur without any compensatory advantages.

XXXVIII.—The Constitution of Silica Bricks.

By Alexander Scott, M.A., D.Sc.

Introduction.

THE widespread use of silica as a refractory material in the manufacture of steel in open hearth furnaces and in other processes involving high temperatures has rendered necessary a knowledge of the constitution of silica bricks, both in the unused state and after use under various conditions. The material from which the bricks are manufactured consists essentially of quartz, but during manufacture and use this is converted to the other forms of silica, tridymite and cristobalite. It will be necessary to consider not only these transformations and their effects on the physical properties of the bricks, but also the extent to which they are influenced by the impurities present in the original rock and by the various foreign materials, such as furnace dust and so forth, introduced during use. Owing to the great differences in the properties of the various polymorphic forms of silica, chemical analyses alone yield comparatively little information regarding the possible behaviour of a brick and must, therefore, be supplemented by microscopic examination and the application of physical tests. In the following, an account is given of the micro-examination of used and unused bricks, and certain conclusions are derived from the results.

Examination, by reflected light, of a polished surface often yields a considerable amount of information regarding the general texture. The simplest plan is to cut the brick longitudinally by means of a thin carborundum disc, rotating at a high speed, which gives a surface sufficiently smooth for low-power examination. A sheet of glass is then cemented to this by means of Canada balsam and the surface examined with the aid of a lens.[1] In many cases the structure is thrown into relief sufficient for the purposes of examination by moistening with water or coating with varnish. The chief defect of this method is that, by it, it is practically impossible to determine which of the various modifications of silica are present. There

1 Cf. J. W. Mellor, *Trans. Faraday Soc.*, 12, p. 137, 1917.

is, however, no difficulty in doing this, if a thin section be examined by transmitted light according to ordinary petrographic methods. In this way it is often possible to render the determinations quantitative and at the same time examine the finer details of the structure much more quickly than can be done by the former method. Although, in the last resort, very fine detail can be discriminated best by reflected light, the time involved in the preparation of sufficiently well-polished surfaces militates against the use of this method.

The identifications are made, in the usual petrographic manner, by means of the optical properties, and numerous accurate data for these, not only in the case of the silica minerals,[2] but also for the various silicates which it may be necessary to consider, are to be found in the papers dealing with the work of the Geophysical Laboratory. It is impossible to pay too high a tribute to the work of this institution as so many of the recent advances in our knowledge of silica and the silicates are due to its results. Though their investigations have been carried out with chemically pure material and under carefully regulated thermal conditions, it is often possible to apply the results to the phenomena observed in actual practice where in general many impurities are present and the control of temperature is much less rigid.

Most of the earlier work on silica bricks is summarized by Endell,[3] who also carried out a number of investigations on used and unused material. In the last few years a number of papers by various German workers have appeared, while much valuable work has been done by Le Chatelier[4] and his assistants. Fairly comprehensive papers containing numerous physical data have recently been published by two American workers, Seaver[5] and McDowell.[6] Accounts of the work done in this country in recent years are to be found in the Transactions of the Faraday Society (vol. 12) and of The Ceramic Society (vols. 14—17). References to the individual papers will be made later.

Raw Materials.

Various types of raw material have been used in the manufacture of silica bricks, and there have been considerable differences of opinion concerning the relative merits of these.

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2 C. N. Fenner, *Amer. Journ. Sci.* (4), **36**, pp. 331-84.

3 *Stahl u. Eisen*, **32**, pp. 392-7, 1912.

4 La Silice et les Silicates (Paris), 1914; *Rev. de Met.*, **14**, pp. 73-83, 1917; *Trans. Cer. Soc.*, **17** pp. 1-10, 1917.

5 *Trans. Amer. Inst. Min. Eng.*, **53**, pp. 125-39, 1915.

6 *Ibid.* Bull, **119**, pp. 2001-55, 1916.

Grum Grzimailo[7] states than any quartzose rock containing over 94 per cent. SiO_2 will yield good silica bricks, but at the same time he recognises that certain quartz rocks require more prolonged heating for conversion to tridymite, and hence that neither vein quartz nor coarse-grained pure quartzites form such good bricks as more fine-grained but less pure material. Endell[8] remarks on the advantage of using pure quartzite for the larger fragments with less pure material for the groundmass, and he endorses Holmquist's view concerning the friability of quartz grains with undulose extinction. Lange[9] discusses the properties requisite for good bricks and gives numerous analyses of the quartz rocks used on the Continent. He emphasises the importance of structure and composition and holds that the total amount of fusible material—iron oxide, alumina, lime, etc. —should not exceed 3 per cent.

Wernicke[10] is in agreement with Endell, but criticises the conclusions of Grum Grzimailo. From a consideration of Lange's analyses he shows that the usability of a quartz rock cannot be determined by chemical means alone, and consequently he advocates micro-examination. According to this author, most palæozoic quartz-rocks are useless from the point of view of the brickmakers, owing to the lack of amorphous cement, the quartz grains simply forming a mosaic. The cainozoic rocks, on the other hand, consist of isolated quartz grains set in an apparently amorphous groundmass, and are therefore to be preferred. Endell[11] investigated the effect of heating various types of quartz rocks to high temperatures and reached conclusions similar to those of Wernicke. Khoétsky[12] states that certain types of rock such as schistose quartzites, grits, etc., are of no value for brickmaking, partly on account of their structure and partly on account of their variability of composition.

The above conclusions, according to other experience, are by no means universally valid. So far as chemical composition goes it is agreed that a high silica content is necessary, but at the same time a small quantity of other oxides is essential. Diminution in the amount of silica will lower the refractoriness, as during manufacture most of the impurities, such as lime and alumina, combine with the silica to give silicates, and these are

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7 *Rev. de Met.*, **8**, pp. 275-288, 1911; *Stahl u. Eisen*, **31**, pp. 224-6, 1911.

8 Loc. cit.

9 *Stahl u. Eisen*, **31**, pp., 1727-37, 1912.

10 *Stahl u. Eisen*, **33**, pp. 235-60, 1913. See also Wernicke and Wildschrey, *Tonind. Zeit.*, **24**, pp. 262-5, 1910; *Stahl u. Eisen*, **30**, p. 528, 1910.

11 *Stahl u. Eisen*, **33**, pp. 1770-75, 1855-60, 1913.

12 Abstract in *Rev. de Met.* **12**, pp. 143-5, 1915.

sometimes actually molten under the conditions in furnace practice. Hence it is essential that the amount of impurity be kept low, preferably under 5 to 6 per cent.

Comparatively little is known concerning the relative effects of the various impurities. Alumina and lime react with excess of silica to form sillimanite and calcium metasilicate respectively, the melting point of the former being 1810° and the latter 1540°. The ternary compounds of lime, alumina and silica have also melting points which come within the range of temperatures attained in furnace practice. Ferric oxide, on the other hand, does not combine with silica to any extent, but is generally found in the brick in the form of hæmatite, magnetite, or possibly a solid solution of the two. If the brick be subjected to a reducing atmosphere, however, the easily fusible ferrous orthosilicate, fayalite, may form. (Ferrous metasilicate has not, so far, been proved to exist under these conditions.) In some cases calcium ferrous silicate with a melting point of about 1,030° (?) may form. The temperature at which any part of a brick becomes molten will be slightly lower than those given above, and locally may tend to approach the eutectic temperatures of silica and these silicates.

Apart from the easily fusible ferrous salts, however, the chief point is not so much the temperature of fusion, or even the eutectic temperatures of these silicates and silica, as the effect of the molten material on the transformation of the quartz to the high temperature forms. These transformations are greatly accelerated by the presence of a flux which dissolves the quartz and reprecipitates it as one of the high temperature modifications. Obviously an inversion will take place with greater rapidity even in so highly viscous a liquid as a molten silicate than in a solid medium where the rate of diffusion must be considerably slower. Hence a small quantity of relatively fusible material is necessary, not only in the matrix of the brick but also in the ganister fragments, in order that the conversion of the quartz may take place as rapidly as possible. Calcium silicate is certainly more potent than aluminium silicate in accelerating the inversions. Its much lower melting point and its greater ability to dissolve quartz at the temperatures of furnace working must be held responsible.

The structure of the quartz-rock is of very considerable importance. Wernicke's conclusions are disproved by the fact that good silica bricks are made in America from quartzites of early palæozoic age (Ordovician, etc.). These have originally been sandstones, with rounded quartz grains cemented by secondary quartz outgrowths, but later metamorphosed to form a mass of interlocking quartz crystals with little visible non-

siliceous cementing material. In this country most of the rocks used in the manufacture of silica bricks are also of palæozoic age (Carboniferous) and certainly have not a structure like the Continental cainozoic rocks. Thus a typical ganister from the Sheffield district[13] consists of an interlocking mosaic of angular and subangular quartz grains with comparatively little intervening cement and more or less equigranular. The grains are cemented by thin layers of aluminous and ferruginous material which cannot be discriminated microscopically. Generally a trace of mica and other impurities is present. Other English rocks are similar, the chief differences lying in the amount of impurity and variation in size and shape of grain. Some rocks which are used for the production of bricks not of the first grade have more rounded quartz grains and in structure tend to approach sandstones. One point which is of importance is the way in which the rock breaks up. In general, other things being equal, a rock which breaks readily into angular fragments will yield a better brick than one which breaks into rounded fragments. This is to be expected, since a brick with rounded rock fragments, like an analogous sandstone, will have a lower mechanical strength than one with angular material. In general, a rock with rounded quartz grains will not break up to give angular material so readily as a rock with angular quartz crystals. Certainly few of the British and American rocks fulfil Wernicke's condition that the quartz grains should be distinctly separated from each other and embedded in an amorphous cement.

On the other hand, so far as experience in this country goes, pure metamorphic quartzites do not in general yield first class bricks, owing to the absence of the impurity necessary to hasten the conversion of the quartz. Vein quartz suffers from the same disadvantage, while in addition the greater amount of occluded gas is likely to prove troublesome. The writer is inclined to disagree with Wernicke's statement that the effect of the occluded gases is negligible. Vein quartz when heated alone tends to shatter with such readiness that it seems probable that similar effects would appear in the kiln-firing of the brick with the resultant development of local weakness.

So far as our present knowledge goes, the properties requisite in a quartz-rock for the production of silica bricks are (1) high content of silica, (2) presence of small quantity of impurity, insufficient to lower the refractoriness appreciably but sufficient to accelerate the conversion of the quartz, (3) type of structure such as will give angular fragments on crushing,

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13 Cf. Fearnsides, *Trans. Inst. Min. Eng.*, 52, pp. 261-96, 1917.

to maintain mechanical strength. In addition, the usability of a brick depends also on certain factors involved in the manufacture, *i.e.*, grain size and grading of material, type of bond added and duration and temperature of firing.

Unused Bricks.

Descriptions of the microscopic appearance of unused bricks have already been given by several authors.[14] The chief point of interest lies in the conversion of the original quartz to cristobalite and tridymite, since, so long as this is incomplete, there is a liability to expansion on the part of the brick. The experiments of Fenner,[15] Smits and Endell[16] and others have proved beyond doubt the existence of not less than seven crystalline modifications of silica, and it is certain that each of these is present in the brick at some stage of its history., The original α-quartz, during the kiln-firing, changes to the β form, which then tends to go over to cristobalite and tridymite. As has already been pointed out, quartz, tridymite and cristobalite each exist in at least two forms, α and β, and the α–β inversions are reversible and occur with great rapidity. Thus the cold brick always contains the α forms but at high temperatures, it is the β forms that are present. Hence if a brick is liable to be subjected to alternate heating and cooling, it is necessary to consider the sudden volume changes which may occur during the α–β inversions. According to Le Chatelier[17] the α–β inversion in the case of quartz, occurring at 575°, is accompanied by a linear expansion of 0·4 mm. per 100 mm., in the case of cristobalite, at about 230°, an expansion of 1·0 mm. per 100 mm., and in the case of tridymite, at 130° and 160°, an expansion of 0·15 mm. per 100 mm. Hence, so far as this is concerned, a brick composed of tridymite will undergo much smaller volume changes during heating and cooling than one composed of cristobalite or quartz.

The changes which the brick undergoes during kiln-burning have already been described[18]. Prior to firing, the brick consists of ganister fragments set in a matrix of quartz grains of varying sizes and the added bond, which is generally lime or clay. During the firing the bond reacts with some silica dust to form silicates, while the remaining fine-grained quartz

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14 Le Chatelier, loc. cit. Endell, loc. cit. McDowell, loc. cit. Scott, *Trans. Cer. Soc.*, **17**. pp. 137-152, 1917.

15 Loc. cit.

16 *Zeit. Anorg. Chem.*, 80, pp 176-84, 1913.

17 *Rev. Univer. des Mines* (5), 1., p. 90, 1913.

18 Scott, loc. cit.

is converted first to cristobalite and afterwards to tridymite. The larger quartz crystals begin to alter round the margins, and so do the ganister fragments. The most probable explanation is that the silicates partly melt, dissolve the quartz and reprecipitate it as cristobalite, which later converts to tridymite. The alternative theory that the bond acts as a catalyst seems less feasible. One fact in favour of the former is that where the ganister contains a fine-grained cement conversion goes on throughout the fragments wherever any of the cementing material occurs.

As this conversion is irreversible it is advisable that it be carried as far as possible during kiln-firing, but unfortunately most bricks, as put on the market, contain much residual quartz. Table I shows the percentage of unaltered quartz in a number of bricks which have undergone no further heat treatment since they were manufactured.

TABLE I.

British—	No. 1	2	3	4	5
Percentage of quartz by volume ...	52·4	50·6	44·0	42·9	35·7
German—	No. 6	7	8	9	10
Percentage of quartz by volume ...	44·1	42·6	44·6	41·5	49·2
American—	No. 11	12	13	14	15
Percentage of quartz by volume ...	27·7	25·8	23·6	22·6	26·0
Swedish—	No. 16	17			
Percentage of quartz by volume ...	50·5	44·5			

It is of course obvious that the duration and temperature of firing have varied within wide limits, but at the same time other factors have influenced the conversion. Of the British bricks, no two of which were of the same make, No. 1 was made from a coarse-grained rock, and even the crystals of the matrix were comparatively large. In No. 2 the grain size of the crystals was not so large, but rock fragments of fair size formed an unduly large proportion. This coarseness of grain, in each case, is no doubt partly responsible for the large amount of residual quartz. No. 3 was composed of a highly siliceous fine-grained rock with little visible interstitial material separating the quartz crystals, while the ganister fragments were wholly unconverted. The conversion has no doubt been hindered by the lack of non-siliceous cement in the original rock. Nos. 4 and 5 had been made from similar rocks, apparently fairly even-grained ganisters. (The rock of No. 5 contained 3·4 per cent. non-siliceous material.) Both showed signs of having been well fired, as in each case the matrix was practically all converted, while a certain amount of cristobalite was visible in

the rock fragments. The latter had not only altered peripherally but some of the quartz crystals of the interior showed some change. The smaller amount of quartz in No. 5 was apparently due to the presence of pre-burned grog, as some fragments of moderate size showed no residual quartz and even had minute crystals of tridymite. A fair amount of the latter occurred in the matrix in both cases.

Nos. 6 and 7, which were of the same brand, were composed of a coarse quartz rock with abundant dark interstitial material which could not be discriminated under the microscope. No. 8 was made from an even-grained quartz rock which was practically holo-crystalline. The converted material was mainly in the matrix and in a few grog fragments which occurred sporadically throughout the brick. The rock of No. 9 resembled that of No. 6. The evidence of Nos. 6, 7 and 9 indicate that the "amorphous cement" does not favour the conversion to any great extent, as the condition of the matrix showed that in each case the bricks had certainly not been fired less than usual. Nos. 11, 12 and 13 were typical American bricks made from quartzites of early palæozoic age. The figures for Nos. 14 and 15 are those given by Seaver[19] and McDowell[20] for similar bricks, and they confirm the results obtained by the writer. As neither the composition nor structure of the original rocks is such that the conversion of the quartz is likely to be unusually accelerated, the explanation of the low percentage of the latter is to be found in the firing. Not only is the duration of the firing much longer but it is carried out at a higher temperature (cones 15—17, and even higher) than is usual in this country. Nos. 16 and 17 were composed of fragments of fine-grained metamorphic quartzite with angular crystals and a slightly schistose structure. The rock fragments were practically unaltered with the notable exception of a few which consisted entirely of tridymite and cristobalite and which probably represented grog fragments. The nature of the matrix suggested that the bricks were fairly well burned, and the relatively high proportion of quartz is to be attributed to the nature of the original rock.

The evidence of these bricks, as a whole, is that the structure of the original rock has a fairly strong influence on the conversion, but that in some cases the latter may be assisted by improved firing. There is no doubt that many of the above-mentioned bricks, if fired to cone 16 or 17, for the same time as they have been fired at a lower temperature, would show a

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19 Loc. cit.

20 Loc. cit.

much smaller amount of quartz. At the same time the proportion of quartz could also be reduced by more prolonged firing at, say, cone 12, but some tests recently carried out suggest that the time required is liable to be inordinately long.

Used Bricks.

A considerable amount of information concerning the changes which occur on further heating can be obtained from the examination of used bricks provided the conditions to which the latter have been subjected are known. Since, in practice, a brick is rarely at a uniform temperature throughout its whole volume, sections have been prepared from different parts of each brick, and thus the behaviour of the brick through a definite range may be ascertained. Where the brick has suffered little contamination from foreign material the principal changes which occur are concerned with the conversion of the quartz to the high temperature forms. Passing from the cool to the hot end of the brick the amount of quartz steadily diminishes, while the amount of cristobalite and tridymite increases. A brick, the hot end of which had been at approximately 1,550° for many months, was made up of these constituents in the proportions given in Table II, the numbers at the top of each column indicating the distance in centimetres from the hot end.

TABLE II.

	1	12·5	20
Quartz	0·0	10·8	20·4
Cristobalite ...	1·9	59·0	71·1
Glass	6·7		
Tridymite ...	91·4	30·2	8·5

In the cooler parts it is impossible to discriminate the constituents of the matrix to any extent, but an examination of powdered material shows that it consists mainly of cristobalite. Similarly in the last two columns of Table II the figures for tridymite are probably too low, as they include only such material as could be definitely identified as tridymite under the microscope. The proportion of quartz reaches zero some distance from the hot end. These sections offer some confirmation of the theory that the conversion occurs through the solution of the quartz by the molten silicates of the matrix, reprecipitation of the dissolved material as cristobalite and conversion of the latter on prolonged annealing to tridymite. In sections of the hottest parts much of the cristobalite appeared as well-developed skeletons in the midst of glassy areas, and hence it seemed probable that these skeletons developed during the cooling

of the brick. Prolonged annealing of a small piece taken from the hot end of such a brick, at a temperature of approximately 1,400° C. followed by quenching, showed that these skeletons have redissolved to a certain extent, but the tridymite was practically unaltered. Consequently, it is feasible to assume that when the brick is at a temperature of 1,550° C. the matrix consists of a molten (though very viscous) saturated solution of silica in silicates of calcium, etc.

Throughout these changes the fine material of the matrix is always at a more advanced stage than the ganister fragments. While the latter are still in the form of unconverted quartz the silica of the matrix has changed to a fine-grained micro-crystalline aggregate of, apparently, cristobalite, except of course that proportion which has reacted with the bases present to form silicates. At a further stage the fragments change peripherally, and in some cases so do the individual quartz crystals, but at the same time the conversion of the matrix to tridymite has commenced. Even when all the quartz has disappeared it is usually possible to distinguish the original rock fragments by the fact that they consist either of cristobalite or very fine-grained tridymite, while the matrix is made up of coarse wedge-shaped crystals of the latter. Similarly, grog, in the form of fragments of old brick, which may have been added, can be distinguished as the tridymite there is comparable in development with that of the matrix rather than the rock fragments.

The evidence of these bricks tends to confirm the idea that tridymite is the stable form of silica up to at least 1,550°. The fact that bricks containing about 97 per cent. silica are mainly or practically all tridymite after being at this temperature for very prolonged periods is confirmatory of this, as it seems very improbable that such comparatively coarse tridymite could develop during cooling. In order to test this a piece of brick, which microscopically showed nothing but tridymite, was held at a temperature of about 1530° for two weeks and then quenched. So far as could be observed the tridymite was unchanged. Where cristobalite occurs its production can generally be traced to precipitation from molten material, probably during cooling. This is shown by the habit and occurrence of the cristobalite crystals and by the partial solution of the latter during some annealing experiments (see above).

Where the bricks have been contaminated by foreign material such as dust, volatilized oxides, etc., the effects vary with the nature of the latter. In one series which was examined the bricks had been subjected to attack by volatilized alkalies. This resulted in a much greater tendency to the formation of

glass, as thin sections showed a fair proportion of colourless non-crystalline material which was probably a glass composed of alkaline silicates. The end which had been attacked showed a much higher proportion of cristobalite than a similarly heated unattacked brick, but within two centimetres of the hot end the section showed nothing but tridymite. The cristobalite-rich area was confined to those parts which were probably molten under working conditions.

Where the bricks have been used in a steel furnace and the foreign materials have been mainly iron oxides different effects are observed. As is well known, a brick from the roof of a steel furnace exhibits megascopically several distinct layers. The hottest end is generally grey in colour and shows little trace of the original fragments. This layer, which may be as much as 3 cm. in width is succeeded by 4—6 cm. of black material, partly structureless but showing traces of the original brick structure on the cooler margin. Beyond this is a band 7—10 cm. in width of pale-coloured brick resembling the unused material, though the fragments are much less distinct. Finally, the cool end is decidedly red in colour, except for a narrow layer of apparently unaltered material at the extreme end.

Microscopically the cooler portions resemble those of the bricks described above. The amount of unaltered quartz diminishes as the hotter parts are approached, while the amount of visible tridymite increases. In the red part the rock fragments are little altered, but the matrix is partly converted to a very fine-grained aggregate which seems to be mainly cristobalite. The iron oxide, to which the colour is due, appears as thin irregular plates of hæmatite. In the pale-coloured part the hæmatite does not appear, while the conversion is somewhat more advanced. About the middle of the brick the larger quartz crystals show an aureole of cristobalite and the amount of quartz diminishes rapidly. Where the diminution in quartz is most apparent an appreciable amount of tridymite begins to appear. The colder margin of the black layer shows an absence of quartz, while the matrix is an aggregate of interlocking tridymite crystals. The rock fragments, however, can always be identified by the small grain size of the crystals. In some cases "lanes" of moderately coarse tridymite appear in the midst of a rock fragment just as the earlier conversion of the quartz often occurs.

The black colour is due to the presence of iron oxide, which seems to be mainly magnetite. This in general is confined to the matrix and rarely penetrates the rock fragments. It generally encloses the tridymite crystals, the arrangement closely resembling the "ophitic structure" of certain igneous

rocks. Occasionally the iron oxide has reacted with the silica to form minute skeletal crystals which are probably fayalite. It is possible that these crystallize out of solution during the cooling of the brick. The fact that the magnetite fails to penetrate the rock fragments enables the latter to be easily recognised, though, in the case of a few grog fragments, thin layers of magnetite are visible between the tridymite crystals. As the grey zone is approached the grain size of the crystals becomes greater while the cristobalite is replaced by tridymite, the latter being the main constituent even of the fragments. In some cases these contain a large number of minute particles of magnetite.

The grey zone, however, shows more variety of constitution. In some cases the structure is very like that of the black zone. The section shows the silica to be present mainly as well-developed crystals of tridymite, though locally some cristobalite is visible. The former is, for the most part, surrounded by plates of magnetite which fills the interspaces between the crystals. The rock fragments contain a fair amount of magnetite, but these, except occasionally at the extreme edge, are still distinguishable. In addition much magnetite "dust" is disseminated throughout the section. Locally the iron oxide forms a reticulate structure, with the silica, which is then mainly cristobalite, in the interspaces. The total amount of fayalite is small, but most of it is found associated with the latter type of structure.

In other cases, however, the whole section is made up of this type of structure. The form of silica which preponderates is cristobalite, generally in minute rounded crystals, though a fair amount of tridymite also occurs. These crystals are enclosed in groups in a network of magnetite. Numerous small skeletal crystals of fayalite can be distinguished under a high-power objective. All trace of the original rock fragments has disappeared and the section is practically homogeneous. It is very probable that, at some period, when the brick was in the furnace, the portions which now show this structure were practically molten, and the crystals now to be seen have mainly developed during cooling. In fact, the disappearance of all traces of the original fragments may be regarded as one criterion for the existence of a liquid phase at some stage of the brick's history. In the present case there was probably, at some period, a layer of very viscous molten material at the hot end. In the former case there has only been local melting, the major portion of the brick having apparently maintained its solid condition. The existence of the fayalite in greater amount in the cristobalite-rich parts may also be regarded as indicative of conditions more favourable to the occurrence of reaction between the iron

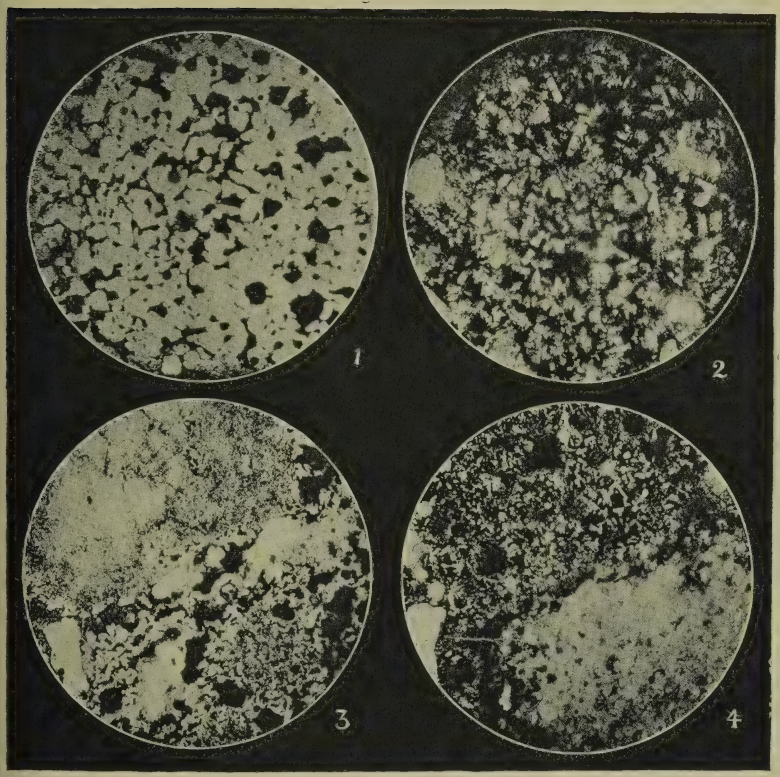

Fig. 1. Silica brick from roof of steel furnace, 1 cm. from hot end. Shows irregular network of magnetite enclosing silica which is mainly cristobalite. x 75.

Fig. 2. Silica brick from roof of steel furnace, 5 cm. from hot end. Shows typical structure of matrix with well-developed crystals of tridymite enclosed by magnetite. x 40.

Fig. 3. Silica brick from roof of steel furnace, 2 cm. from hot end. Coarsely crystalline portion is matrix and is composed of tridymite and magnetite. Rest is part of original rock-fragment made up of fine-grained tridymite and permeated with magnetite dust. x 40.

Fig. 4. Silica brick from port of steel furnace, 2 cm. from hot end. Clear area is rock-fragment containing some residual quartz. Rest is matrix composed of tridymite and altered fayalite (dark material). x 30.

oxide and the silica, while the skeletal form of the crystals is suggestive of crystallization from a viscous "melt."

One notable point is that in the grey zone the proportion of magnetite is decidedly less than in the black zone. The amounts at various distances from the hot end are given in Table III, and Curve II of figure 5 shows the variation of this with the distance from hot end.

TABLE III.

Distance from hot end in cm.	...	5	3	1
Percentage of magnetite	...	34·6	33·0	21·6

Another interesting point arises in connection with the conversion of the quartz in these bricks from the roof of a steel furnace. The proportions of unaltered quartz were measured in a number of sections and plotted against the distance of

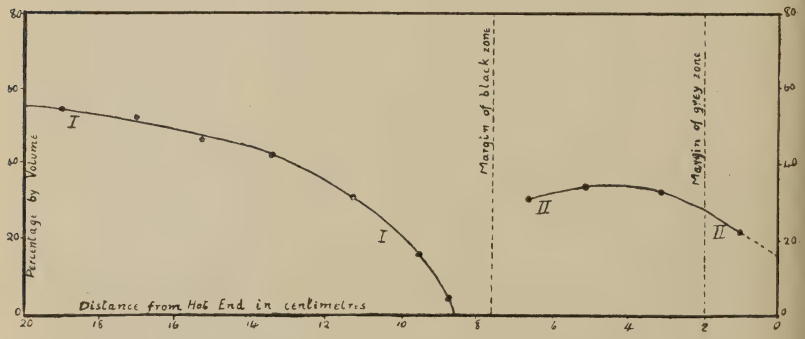

Fig. 5. Curve I shows the proportion of unaltered quartz at various distances from hot end of silica brick from roof of steel furnace, and Curve II the proportion of magnetite.

the centre of the section from the hot end of the brick. As the sections average 1·5 cm. in width, the measurements only give the mean amount of quartz in the neighbourhood of the point indicated. The measurements are given in Table IV.

TABLE IV.

Distance from hot end in cm.	19·0	17·0	15·3	13·5	11·2	9·5	8·5	7·5
Percentage of unaltered quartz	53·8	52·0	44·8	40·1	30·7	16·0	3·8	0·0

A consideration of the curve (I in fig. 5) shows that the slope alters fairly sharply between 8 and 10 cm. from the hot end, that is at a point 1 to 3 cm. from the margin of the iron-oxide-bearing portion. The greater degree of conversion cannot be

directly due to the iron oxide as there is no appreciable quantity of the latter in the region where it occurs. Nor does it seem possible that any temperature differences can be held responsible. It is most probably due to some variation in composition, such as a local concentration of the fusible materials, but in the absence of analytical data the exact nature of such variation cannot be determined.

Bricks which have been in the port of a steel furnace differ considerably from those from the roof. Several bricks which had been in furnace ports for prolonged periods were sectioned as described above and examined. In each case the iron oxide has penetrated to a distance of at least 10 cm., and some of the bricks have been denuded to a considerable extent. Sections of the light coloured parts show a strong resemblance to the unused brick except for the greater degree of conversion of the quartz. This only applies to the matrix, as in each case the rock fragments were pratically unaltered. A section in the black area, near the boundary, shows a great abundance of black oxide in the matrix but no penetration of the fragments. The latter, however, have been attacked round the margins, as they show a "reaction-rim," which seems to be mainly fayalite.

As the hot end of the brick is approached the crystals of tridymite increase in size, while the rock-fragments diminish by corrosion and are replaced, in some cases, by masses of silicate. The corrosion rims round the larger ones are very well marked. Even at the hot end the quartz has not entirely disappeared, while many of the fragments maintain their individuality. They consist of cristobalite, tridymite and quartz in varying proportions, but are usually free from iron compounds except for the rim of fayalite. The matrix is made up of tridymite, in fairly coarse crystals, iron oxide and fayalite. The last sometimes develops in large crystals exhibiting a well-defined cleavage and a characteristic mode of alteration. It is red to brown in colour, has high refractive index and high double refraction, and has straight extinction. It often occurs intergrown with tridymite, the latter being idiomorphic towards the former. This co-occurrence of the two minerals is interesting, as it indicates the instability of ferrous metasilicate at the temperatures to which these bricks have been subjected. In another brick, which had not been heated to such a high temperature, some small crystals were observed which might be metasilicate. They differed from the above in having oblique extinction. It is also possible, of course, that they may have contained manganese or other base, and hence they cannot be certainly regarded as ferrous metasilicate. So far, such evidence as we have points to the latter being unstable

at high temperatures, particularly as the only naturally occurring mineral of this composition, grünerite, is an amphibole and therefore probably a relatively low temperature modification.

The chief difference between the bricks examined lay in the behaviour of the rock fragments. In some cases the latter corroded marginally at a uniform rate, but in others embayments tended to form, and ultimately "lanes" of fine-grained fayalite developed. This difference of behaviour is to be traced to differences in the original rock. The amount of quartz at the hot end is also variable, but not to any great extent. It probably depends on the grain size of the crystals in the original rock. This persistence of the quartz is to be attributed probably to the fact that these bricks have a shorter life than those of the roof, the duration of heating being an important factor in the silica transformations.

The notable tendency to "slagging" is connected with the amount of fayalite. The fact that the bricks are periodically subjected to the action of reducing gases results in the formation of the reactive ferrous oxide, which readily combines with silica to give fayalite. Further, the corrosion is favoured by the easily fusible nature of the latter. Another factor which influences the corrosion is the porosity of the brick. In some cases the iron oxide can penetrate the brick much more easily than in others, and there is no doubt that the penetration depends partly on the porosity.

While the microscopic examination of used bricks may not lead to many results which are directly of importance to the maker and user, such a study seems to the writer a necessary prelude to more exact work. It at least gives some clue as to the nature of the reactions between the refractory materials and the corroding agents, while at the same time a certain number of deductions can be made concerning the condition of the bricks while in actual use. It is hoped that it may be possible to supplement the above by work of a more directly experimental nature, and indeed one reason why the examination was undertaken was the determination of the problems involved.

In conclusion, I wish to acknowledge the great kindness of Mr. D. J. Pinkerton, who has provided me with numerous samples of used material of many kinds and from various parts of furnaces. I am also greatly indebted to Mr. N. Stein for samples of unused bricks of foreign manufacture.

XXXIX.—Note on the Microstructure of Magnesite Bricks.

By Alexander Scott, M.A., D.Sc.

ALTHOUGH the literature dealing with raw magnesite, from both geological and chemical standpoints, is fairly voluminous, comparatively little has been published concerning magnesite bricks. Most of the earlier papers on magnesite are discussed by Redlich[1] and references to those more recent are given by Wilson[2] in his account of the American deposits. Redlich also devotes a section to the microstructure of magnesite bricks, but this is mainly a rescript of an earlier paper by Cornu[3]. In this is noted the occurrence of the crystalline form of magnesia, periclase, together with black opaque crystals showing well developed cubic cleavage and identified as the spinel, magnesioferrite ($MgAl_2O_4$). H. B. Cronshaw[4] has also given a petrographical description of a magnesite brick in which was found periclase associated with two minerals whose nature was not definitely proved. One was doubtfully identified as quartz and the other, which occurred as brownish-red isotropic crystals with well-developed rectangular cleavage and high refractive index, as magnesioferrite.

The structure of raw magnesite varies greatly from coarsely crystalline rocks to material which is apparently amorphous; but as no investigation of the effect of the structure of the raw material on the properties of the manufactured brick has been made, the microstructure of raw magnesite need not be further considered here; in any case it is very probable that, no matter what the original nature of the material may be, the calcined product is reduced at some period to an amorphous magnesia. The latter, however, tends to convert to the crystalline form, periclase.

Under the microscope calcined magnesite appears to be a very fine-grained amorphous mass of magnesia, with local doubly refracting areas containing the impurities. If the material be calcined at higher temperatures, or for more prolonged periods crystallization of the magnesia is initiated and the crystals of periclase can be observed under the microscope in a section of "deadburned" magnesite. A similar development of crystals occurs in bricks during the kiln-firing.

An examination of magnesite bricks shows that two well defined types of structure exist and that gradations between these two are common.

In the first type, the magnesia occurs as sharply defined polygonal crystals of periclase which form a reticulate aggregate. The periclase has the typically high refractive index, is isotropic and often shows a very well-defined rectangular cleavage. It is generally brownish to red in colour, apparently owing to the presence of disseminated iron oxide, and contains, as inclusions, small dark crystals of magnesioferrite. The crystallization of the latter seems to be anterior to that of the periclase which invariably encloses it. Locally the remainder of the impurities in the original rock crystallize mainly as silicates, and these are sometimes found forming doubly refracting layers between the polygonal grains of periclase.

Cronshaw[4] identifies the red material with cubic cleavage as magnesioferrite, but it is much more probably periclase containing some oxide of iron or ferrate of magnesium in solid solution. Occasionally bricks are observed in which the predominant mineral is of this nature, and in these cases it cannot be magnesioferrite. Further, the microscopic appearance does not agree with that of the latter. Magnesioferrite, which belongs to the spinel group, is a nearly opaque cubic mineral, and in thin sections often shows a considerable resemblance to magnetite. The crystals under question, though coloured by disseminated iron oxide, are obviously translucent; the refractive index is practically that of periclase, and the only point in which they differ from the latter is in the development of a well-defined cleavage. Periclase often shows an ill-defined cleavage, and it is conceivable that in this case the presence of some foreign material, as suggested above, may have increased the tendency for the development of the cleavage. Further, bricks have been examined showing an 80 per cent. proportion of this cleaved mineral, and as the bricks contained less than 6 per cent. iron oxide the mineral could not possibly be magnesioferrite, the theoretical composition of which is approximately 80 per cent. Fe_2O_3 with 20 per cent. MgO. The black material which is found in those portions of a magnesite brick which have been in contact with the reaction products of a steel furnace is undoubtedly in part magnesioferrite, but it bears no resemblance to the material described above. Hence this brownish-red isotropic mineral with the cubic cleavage must be regarded as periclase containing some other substance in solid solution. In this connection it may be noticed that there is a notably greater development of cleavage in those bricks containing from 4 to 7 per cent. iron oxide, which would

indicate that the substance in isomorphous mixture with the magnesia is some iron compound.

The second type of crystallization is very different. The magnesia appears as small rounded crystals in a matrix which is generally crystalline, but which seems to have a fairly low melting point, as one brick which had been quenched from a temperature of 1,500° C. showed traces of glass in the matrix. The grain size of the periclase is very variable even in a single brick, the crystals sometimes being so small as to be discriminated only with the aid of an $\frac{1}{8}$ in. objective, while at other times they are large enough to be distinguished with the aid of a lens. They are apparently spherical in shape and never have crystal boundaries. The polygonal structure of the first type is absent and adjacent crystals seem to be generally separated by layers of matrix. Enclosures of early-formed magnesioferrite are rarely found in the crystals of periclase in this type.

The composition of the matrix seems to be variable. In some cases a mineral which occurs as lath-shaped crystals with high double refraction and seems to be forsterite occurs. The commonest orthosilicate seems to bear more resemblance to monticellite. It has a moderately high refractive index and a medium double refraction which would agree fairly well with monticellite as the double refraction of the latter is given as 0·017 by Doelter. In used bricks considerable areas of the matrix are in optical continuity. The probability that the mineral is monticellite is increased by the fact that bricks which show this type of structure have an appreciable content of lime and silica.

In a few bricks a somewhat similar mineral with a slightly lower double refraction was observed, and it is possible that this mineral is impure monticellite. The double refraction was similar to that of anorthite, but the refractive index was considerably higher. In some sections of deadburned magnesite another mineral which could not be identified definitely was noticed. The double refraction was like that of quartz, but as the refractive index was equal to or slightly lower than that of Canada balsam it cannot be quartz. As the crystals were very minute no other determination of the physical properties could be made, and the nature of the mineral must be left in doubt for the time being.

With reference to the occurrence of the two types the most notable fact is that the first type is found in those bricks which have iron oxide as the main impurity, while the second type is more common in magnesite containing appreciable quantities of lime and silica. In the former case the iron oxide is partly found as the early-formed magnesioferrite and partly

as disseminated red material. In the latter case the impurities are the last to crystallize and serve as a matrix in which are set the periclase crystals. Consequently it is to be expected that the former would stand much higher temperatures than the latter owing to the lower melting points of the silicates as compared with such a material as magnesioferrite. In many cases, of course, both types of structure are found in the one brick, but in general one or other predominates accordingly as the impurity is mainly iron oxide or mainly lime and silica. At the same time it is doubtful if a magnesite of the latter type can be made to yield products like a raw material of the former type, as what is wanted is not so much the presence of the iron as the elimination of the silicate. It is of course possible that the presence of magnesioferrite would tend to increase the refractory properties owing to its very high melting point, but this increase would be negligible in comparison with the lowering of these properties by the presence of appreciable quantities of relatively easily fusible silicates. For example, according to Pöschl[5] the melting point of monticellite is about 1,460° C., which would mean that a brick containing appreciable quantities of this mineral would have its matrix molten under the conditions occurring in practice.

Another interesting feature which can be observed under the microscope is the crystallization of the periclase. In magnesite as ordinarily burned the magnesia is probably amorphous, but additional firing converts this to the crystalline form. This conversion would occur even if no impurities were present, but it is probably hastened by the latter. There is no doubt that the steady increase in grain-size of the periclase crystals which occurs during further heat treatment is due to the action of the impurities. The latter, being present probably as silicates of lime and magnesia, fuse on heating, dissolve the fine-grained magnesia and reprecipitate it in the crystalline form as periclase. As crystals of the latter are already present these act as nuclei to which the crystallizing material tends to attach itself, and consequently the grain size tends to increase. This is probably the case in both types of crystallization, as even in the first type very thin layers of impurity may exist separating the polygonal grains. The consequence of this increase in grain size is an increase in specific gravity. It is well known that magnesite bricks tend to increase in specific gravity as the number of firings is increased. Mellor[6] has attributed this to the existence of two modifications, α and β-magnesia, and to the conversion of the α into the β-form. As the writer understands it, Dr. Mellor's α-form is practically equivalent to the amorphous material which is the product of calcination of the carbonate,

while the β-form is crystalline periclase. Measurements of the refractive index of the latter were made in one portion of a brick which had been fired once and in another portion of the same brick which had been fired many times, but no difference was to be observed in the values obtained. Hence it seems very probable that there is only one crystalline form of magnesia and that is periclase. The only other modification which seems possible is the amorphous one. The further increase in specific gravity during further burning of material already apparently holocrystalline is to be attributed mainly to the increase in the grain size of the individual crystals and not to transformations to any other modifications.

The examination of sections of used bricks affords further proof of the action of the matrix in aiding crystallization. In many cases the peripheral layers of the grog fragments are comparatively coarsely crystalline; this is followed by a fine-grained band of crystalline material while the core is apparently amorphous. The margin has been in contact with the matrix for a long time, and has not only been converted to the crystalline form but the crystals also have undergone considerable increase in size. The intermediate layer represents material which has only recently been transformed while the core is still in the state of the calcined product. This is proved by the distribution of the impurities. The coarsely crystalline border contains a certain amount of anisotropic matrix, but much the greatest proportion of the latter is to be found in the intermediate layer while it is entirely absent from the core.

In bricks which have been in use for a long time it is often very difficult to discriminate the grog fragments as the whole section shows a uniform structure. In some intermediate types the grog fragments can still be identified, but at their margins they seem to pass gradually into the matrix. In some cases, too, the structure of the first type has a greater tendency to occur in the grog, while a greater proportion of the second type is to be found in the matrix.

The above notes, which are only to be regarded as a preliminary statement of the results so far obtained, will perhaps show how little is known concerning the constitution of magnesite bricks. The writer had hoped to be able to include some further results but unfortunately these are not available at the moment.

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DISCUSSION

(ON THE TWO PRECEDING PAPERS).

Mr. COSMO JOHNS:—It is extremely difficult to discuss a paper like that to which we have just listened dealing with difficult physico-chemical problems involving questions that are still the subject of controversy in the absence of even a brief abstract of the conclusions arrived at. Its importance demands careful study, for the problems discussed are fundamental and must govern any advances made in the study of the siliceous refractory materials. It would appear that the paper records observations that would apparently render invalid the conclusions of Fenner as to the stability relations of the silica minerals. It should not be forgotten that Fenner used pure silica with a sodic-tungstate flux, and that this observer records that at times it was possible to note the simultaneous occurrence of the three mineral forms in the same melt. Dr. Scott, as he does not refer to quenching experiments with melts held long enough at high temperatures to have attained equilibrium, has apparently confined his studies to silica bricks after a long life in a metallurgical furnace. I do not consider that such observations have any bearing on the validity of Fenner's conclusions. You are dealing with a brick of whose original composition and varied thermal history nothing is known. It contains silica particles with unknown impurities; lime made from limestone containing impurities; the brick is burnt for an unknown time at an unknown temperature and cooled at an unknown rate. It is introduced into a metallurgical furnace, heated to and maintained for months at a high but fluctuating temperature exposed to various vapours, and finally cooled at an unknown rate. How it should be thought possible under these conditions to deduce from the mineral forms appearing in the cold brick, after a history entirely unknown, with a flux certainly more complex than anything previously studied, the stability relations at high temperatures is difficult to see. The conclusions of Fenner might be correct or wrong, or as is more probable they only apply to silica in the presence of a sodic-tungstate flux; observations on cold used bricks of unknown thermal history will not solve the difficulty. Nothing short of carefully devised quenching experiments will give the data required. So far as the brick manufacture is concerned the transition point 1,300° C. for the quartz-tridymite inversion *when dry quartz is employed* remains, probably, the most useful temperature. Silica bricks should remain during burning above that temperature at least for a considerable time. I published that determination twelve years ago.

Professor FEARNSIDES said that until he should have had opportunity to peruse the script of Dr. Scott's two papers he was not prepared to discuss the more important of the controversial issues raised. There were, however, two points on which he would like some further information. Speaking of the influence of ferrous salts in silica brick, Dr. Scott had said that their presence was never other than a disadvantage. So far as the speaker had experience of bricks made from Sheffield ganister, which had been burnt off in an oxidizing atmosphere, they were incapable of performing such good service as flame-resisting materials as would exactly similar materials which had been fired and well soaked at the highest attainable temperature in the reducing atmosphere which prevails in the old-fashioned type of coal-fired kiln. In the speaker's opinion this difference of behaviour was to be correlated with the circumstance that the double silicate of calcium and ferrous iron is a more potent solvent of quartz than is the pure lime silicate, and therefore the quantity of quartz which is transformed into tridymite in any given time when ferrous iron is present is greater than the quantity converted when the double silicate of lime and iron has been dissociated and iron is present in the ferric state. Under these circumstances it would be agreed that the presence of salts of ferrous iron in the interstitial bond between the grains of quartz or tridymite is to the silica brick's advantage.

In describing the micro-structure of magnesite bricks Dr. Scott had mentioned the occurrence of ophitic plates of a mineral which has many of the optical properties of quartz and in which the grains of periclase are embedded. In certain Veitsch bricks which had seen long service in the side walls of the steel bath of an electric furnace the speaker had noticed the frequent occurrence of similar rather large ophitic plates or interstitial patches of idocrase, and he wished to ask Dr. Scott whether he had considered the possibility that idocrase might be the mineral which he had observed.

Mr. E. STEIGER:—When listening to Dr. Scott it occurred to me if it was not possible for the Council to get into touch with the Americans? I understand that the Americans mix iron with all the raw magnesite stone intended for conversion into deadburnt magnesite, and later into magnesite bricks. Last year the production of raw magnesite stone in the United States amounted to over 300,000 tons, consequently the subject of the preparation of a suitable deadburnt material has become of great importance to them. Some of the American magnesite brickmakers claim to have successfully solved the problem and to produce a mixture superior in effect to the Austrian and

Hungarian magnesite, because of the uniformity of the synthetic mixture. The Americans have to deal with an ore quite as low in oxide of iron as the Greek ore used in this country, and the result of their investigations will therefore be of considerable value to British makers. The Bureau of Mines at Washington has set aside a sum of $5,000,000 to be spent this year on this very subject. It would be of advantage to the members of the Society if the conclusions arrived at in America could be collected by the Society and communicated in time to the members.

Mr. T. ARTHUR ACTON, F.S.A.:—The president has asked me to make a few remarks on the subject matter of this paper.

As an amateur petrologist who has been muddling with silica rocks for many years—I say muddling advisedly, because the subject seems becoming so technical as almost to be beyond the grasp of the amateur—I venture to remind our members how much we owe to the pure research work of the specialist—and that it is our interest in every way to encourage this class of work, even if we do not see practical results arising therefrom at once. The successful manufacturer of the future will be the one who can note the trend of pure scientific knowledge and apply it to his own special needs.

Petrological investigation of raw and manufactured material appears to be a field of special interest to the manufacturer of refractories.

To-day we are indebted to Prof. Fearnsides for his able paper on the geology of the raw refractory products of this immediate district, and interest especially attaches to his suggested explanation that the Sheffield ganisters were deposited under alternation of marine and estuarine climatic conditions, it is hoped he will further investigate this subject.

As to the use of the term "ganister," Prof. Fearnsides, who has contributed an interesting note, p. 49 in the recent issue of our journal, refers to the question I raised at our last meeting as a thorny one—personally I see no difficulty in Yorkshire geologists deciding which particular rock the term ganister should be applied to. Large quantities of silica bricks are now being made from quartzite rocks of varying geological horizons, especially in America, to which the Sheffield people would not apply the term ganister which, as I understand it, is used locally to denote the silica rock forming the seat of the Halifax Hard Bed Coal in the Lower Coal Measures.

Endell and Lange's papers, published in 1912, of which an abstract appears in our journal, are—like a good many other German theories—now out of date, and many of Dr. Lange's

observations on the use of palæozoic quartzites, in the light of American practice, are quite unreliable.

M. H. Le Chatelier's paper is a most valuable contribution. Further research will probably modify some of his views on the subject of the process of conversion of the various forms of silica. Mr. Fenner's contribution, written, as he states, under disadvantageous circumstances, owing to being engaged on war work, is somewhat disappointing. Referring to Le Chatelier's paper on page 13, there is a microphotograph of a section under polarized light (magnification 200) of a well-fired American silica brick made from a quartzite rock, which shows a beautiful network of tridymite crystals and comparatively little unconverted or raw quartz. This sections agrees with numerous sections I have made and examined of the silica bricks made by the Harbison-Walker Refractory Company of Pittsburgh, Pa., from the Medina rock, a palæozoic quartzite in geological horizon about equivalent to our Llandovery series. Baraboo and Alabama quartzites are also largely used. I have examined all these quartzite rocks and find no material difference to our Welsh and other British quartzites either in chemical analysis or mechanical structure.

I am not aware that the Americans are using any rocks from their Coal Measures series, and before the war the Germans were using tertiary quartzites often containing a proportionately high iron content. I have, of course, not been able to obtain any German bricks recently.

Turning over to Dr. Alexander Scott's able paper, on pp. 142—143 are photos. of used silica bricks apparently showing under a magnification of 30 diam. little or very slight conversion, and Dr. Scott goes on to state that in none of the bricks examined—all of British manufacture—was there anything like complete conversion to tridymite or cristobalite, nor did the proportion of the latter minerals approximate to the values given by K. Seaver for the Harbison-Walker bricks. What is the explanation? I suggest that the bricks examined by Dr. Scott are under-fired in the kiln, and this seems proved by his further remarks and sections of bricks actually used in the steel furnace; but I must say my experience in the examination of British bricks does not agree with Dr. Scott's results, except as compared with American bricks our bricks are not as a rule burnt at such high temperatures as they use, and so contain more unconverted or raw quartz.

I have already taken up more time than I intended to, but should just like to refer to Dr. Mellor's contribution to the discussion on M. Le Chatelier's paper where he puts the present position with his usual clearness, which I epitomise as follows:—

Crystalline silica can be ranged in two classes: ordinary silica with a high, and well fired silica, with a low specific gravity —the low specific gravity forms have the greater volume. We can call the high specific gravity form *A*-quartz, the low form *B*-quartz.

There are two low specific gravity forms, tridymite and cristobalite—the mechanism of the passage from the high to the low specific gravity form is not yet clearly understood, but silica bricks should be burnt in the kiln at a temperature high enough and long enough to convert the greater proportion of raw *A*-quartz into the less dense *B*-quartz.

This is plain English, I venture entirely to agree, and in our present state of knowledge suggest that the best practical test by petrological analysis would be to estimate the proportion of unconverted quartz, leaving the somewhat difficult determination of the proportion of tridymite and cristobalite until the pure scientist has discovered a somewhat simpler method than that suggested by Dr. Scott, pp. 188—191.

I look forward with interest to the paper promised us at our next meeting by Dr. H. H. Thomas, with whom I have had the pleasure of discussing some of these problems.

In reply Dr. SCOTT stated that he much regretted that owing to an unforeseen circumstance it had been impossible to have the papers printed in time for the meeting. He quite appreciated the difficulty of discussing a paper read only in abstract. With regard to Mr. John's remarks, it might be pointed out that Fenner's work was not considered to be invalidated in any way: it was one of Fenner's conclusions that was criticised. This criticism occurred to the writer on first reading Fenner's paper, and it was merely confirmed by the occurrence of such coarse tridymite in bricks which had been subjected for long periods to temperatures certainly above 1,470°. The fact that tridymite can only be made to invert to cristobalite at 1,470° by means of a flux seems to the writer to bear the interpretation that tridymite is stable above that temperature. The cristobalite, appearing between 1,470° and 1,570°, is an example of a less stable phase coming directly out of solution in the flux. Tridymite can only be regarded as unstable in this region if it can be converted, in the absence of a flux, to cristobalite.

A number of quenching experiments have been carried out with materials of known composition, and, as far as they have gone, the results described in the paper had been confirmed. In view of a further extension of this work the discussion of the quenching experiments were omitted from the paper. It might be

pointed out that such a preliminary investigation as is described above is necessary before actual experimental work is undertaken, and that in the only conclusions which have been drawn the variations of thermal and chemical conditions have been taken into account. Geological science would have been much poorer at the present day if all descriptive petrography had been postponed till the Geophysical Laboratory had completed its careful synthetic work. Indeed, in the absence of petrography, the latter would probably not have been undertaken.

The writer agrees with Mr. Acton that a definition of ganister would be welcome. There is an impression, which may, however, be erroneous, that one property necessary for a silica rock which is to be termed ganister is its occurrence in the neighbourhood of Sheffield. Thin sections of the lower palæozoic quartzites used in America seemed to the writer to be somewhat different in structure from our British Carboniferous rocks. With regard to the unused bricks described above, the results were obtained from five random samples of different "makes," and it is most improbable that all should have less firing than usual, particularly as the figures have since been confirmed by the examination of other samples.

In reply to Prof. Fearnsides, the writer was inclined to believe that the presence of much ferrous oxide was likely to lower the refractory properties considerably. The existence of the calcium ferrous silicate must be regarded so far as hypothetical, and hence it seems useless to make any statements regarding its solvent action on quartz. With regard to the possible presence of idocrase, the unknown mineral mentioned above has a much lower refractive index than idocrase, nor have any crystals with a double refraction approaching that of the latter been observed in any of the sections.

Mr. Steiger's suggestion of co-operation with the Americans in regard to magnesite bricks would certainly be worthy of adoption, particularly as they have to deal with raw material as non-ferruginous as the Greek and containing even greater amounts of lime (as in the Grenville deposits) and silica (as in California). If they have solved the problem of obtaining bricks as good as the Austrian their results ought to be applicable to our materials.

XL.—Magnesites and Magnesite Bricks.

By W. Donald.

1.—*Introduction.*

It was largely due to the pioneer work of the magnesite mineowners in Greece that the silica brickmakers in this country started the manufacture of magnesite bricks. In the plants at their disposal the manufacture on more or less primitive lines was possible, and they above all in the country had the ambition to excel in providing the highest refractories. At first the beginning was on small lines as the demand was small, and competition from the Austrian makers was keen; but small though it was, that beginning has stood the country in good stead during the last three years. With the knowledge we have now gained, however, it behoves us to do better in all directions so far as quality is concerned, and it is in the hope that an early presentation of the subject from the manufacturer's point of view will enable us to get the necessary guidance from the users that I propose to give my views on the subject.

In the manufacture of magnesite bricks some of the factors of greatest importance are the following:—

1. What are the most suitable raw materials known?
2. Of these, are there any more suitable than the others?
3. If so, what are the reasons for that high degree of suitability, and how can we best arrive at a knowledge of the subject?
4. For economic or other reasons cannot raw materials from other quarters by proper treatment be made to serve the purpose equally well?
5. Depending on the raw materials to be used, what are the designs of plant best suited to carry on the manufacture and give the best results?

At the present moment the magnesite available in this country is shipped from Greece and India. Other supplies are available in South Africa, Australia, Canada and California.

There are also large deposits in Russia, and smaller deposits in Norway, Sweden and Lapland; the Swedish deposit is very pure but ungetatable.

In former days the supply of deadburned magnesite and magnesite bricks came largely from Austria. That supply was of very high quality, as in the course of 30 years the process of manufacture has been brought to a high degree of perfection by the careful elimination of whatever in the raw magnesite as mined affected deleteriously the life of the finished products in the furnaces in which they were used.

If the manufacture of magnesite bricks is to be carefully studied from the point of view of greater refractoriness of product we must know not only the primary factors relating to the finished bricks, such as (1) weight per thousand of standard size, (2) density, (3) porosity, (4) tensile strength, (5) crushing resistance at high temperature, and (6) average chemical composition; but in order to control these we must know also the factors concerning (*a*) the raw magnesite from which the bricks have been made, including the fullest knowledge possible of the mineral impurities in the magnesite, and the effect on them that heat will have; (*b*) the material at the various stages of manufacture, including the knowledge of the interaction of these mineral impurities with the oxides, magnesia and lime, and the changes that take place individually in each of these oxides; (*c*) the effect of the elimination of certain impurities, and that of the addition of certain others both on the magma resulting from the interaction under heat of such of these impurities with the magnesia particles as are in the finest state of division, and also on the larger particles, including the crystalline nature of these large particles both before and after firing if altered by these impurities; (*d*) the effect on the various particles of very prolonged heating at high temperatures in oxidizing or reducing atmospheres; (*e*) the effect on the crystalline particles or crystalline growths formed at these temperatures of slow or rapid cooling, and (*f*) the effects of furnace heats on the resulting products continued both for short periods at higher temperatures, as in the case of electric furnaces, and for longer periods at lower temperatures in basic open-hearth furnace practice. The used magnesite bricks discarded from furnaces will, on close examination, disclose the action of the furnace temperature, and of the slag or of the oxide dusts (if exposed to either) with which the atmosphere is heavily clouded; as well as the effects of the heat radiating through the furnace walls, causing unequal contraction in different parts of the bricks.

2.—*Microscopic Examination.*

Now if we are to consider this subject in detail in this way we cannot hope to do without optical examination with high magnification; and the more detailed that examination is the more interesting it becomes, disclosing many facts hitherto overlooked; and with sufficient patience in the collection and the comparison of data I am positive that this will be the means by which we manufacturers will be able to form our opinions about the control of our raw materials and finished products. With the microscope we can examine the raw materials in detail and find characteristics that are not visible to the eye. We can examine the main characteristics of the mineral impurities in these raw materials without chemical analysis, and in such a way as enables the management to direct the workers with regard to the elimination of certain impurities either in our factories or even in the mines abroad, as micro-sections can carry the facts to all parts of the world in a way that nothing else can do if there is sufficient knowledge of the microscope at both ends. We can understand the physical changes that come about with the application of heat; the growth of microstructure from the size too small for recognition by the microscope, to what is now apparent to our senses with high magnification, and the various stages of growth that follow on the further application of heat. We can alter amorphous magnesite to massive crystalline magnesite in our factories as well as Nature can do if we apply the right means in a proper way, and the microscope discloses that.

It is the proof by the examination of microscopic sections that I propose to give, in support of the conclusions I have come to; and as I believe the best way to attain a high standard is to have as many facts as possible about the highest standard known in practice, I wish for that reason to bring out certain facts about the microscopic examination of Austrian magnesite bricks first. I shall then deal with the supplies of raw magnesite presently available, showing micro-sections of these magnesites which are all amorphous minerals, and the conversion of these in the first place into crystalline minerals very similar in micro-section to the calcined product derived from the massive crystalline raw magnesite of Austria. Later I shall deal with the production of magnesite bricks from these magnesites according to the standards already reached in our manufacture of magnesite bricks in this country. I shall then indicate the improvements that I think can be brought about.

3.—*Massive Crystalline Magnesite of Austria and Hungary.*

There are two main sources of supply in Austria and Hungary, the one being as far west of Vienna as the other is east from Buda-Pesth, the distance between the two deposits being about 200 miles. The valley in which the Hungarian deposits occur leads into the plains in which are the cities of Buda-Pesth in the south-east and Vienna in the north-west, and towards the Murzthal Valley which leads down to Trieste on the Adriatic; and it is in the minor valleys of Rima and Sago in Hungary, and of Veitsch and Breitenau in Styria, among others, that the most suitable deposits have been worked. There are also other deposits of magnesite in Styria and also in Serbia[1] which contain good rock, but not of this massive crystalline type. The Austrian and Hungarian deposits used for refractories are very similar, as are the bricks made from them. Without going into the matter too fully it will be sufficient for the purpose to consider the deposits of the original mines worked by the Veitsch Magnesite Co., Ltd., since they were opened up by Carl Spæter in 1881. In 1907 that firm had four calcining plants at Veitsch, Breitenau, Eichberg and Trieberg, in Styria.

I give a map of that district to show how wide apart these Styrian deposits are worked. The Veitsch works are the company's headquarters, and it is there only that the magnesite bricks are moulded. Photographs are given of the three first works. In 1907 the fourth was only being erected. These deposits are all worked on the hillside in terraces, the raw magnesite being passed by inclined planes and ærial railways to the dressing stations and calcining kilns in the valleys below. The mineral is described as "of the oldest deposits of the Carboniferous formations, on the outer edge of the Dolomite Hills, and as mined is massive crystalline spar, in appearance not unlike some spathic ironstones, of a yellowish-white to light yellow colour with lamellar grain.[2] There is a specimen from among the breunnerite minerals in the Natural History Museum in London which seems to answer to this description, but the micro-section of that deadburned material which I give (Plate III, Fig. 4) has not characteristics similar to those of the Veitsch deadburned pea-size magnesite. The former is very pure, while the Veitsch deadburned products hold considerable impurities. Other than that, the only definite indication I can give of the appearance of the mineral actually mined by the Veitsch Company is a photograph copied from a print taken from a catalogue of the Chicago Exhibition of 1893. Remembering the photograph of the hills surrounding the works one can well imagine this rock having high specific gravity.

These hill deposits of magnesite in the Eastern Alps of Styria are associated with intrustions of chalybite,[3] a mineral that is itself a ferrous carbonate. Along with that mineral, however, there are constant interpenetrations of chlorite schists and serpentine in particular, but also of many other minerals which are more or less silicates of magnesia with iron and lime, and sometimes alumina and manganese present in variable proportions. The minerals when mined are in some cases passed through washing plants and the most careful hand-picking is carried on both before and after calcination. I have read in a Government report that at one Hungarian works $3\frac{1}{2}$ tons of stone is quarried per ton of deadburned magnesite sold.[4] The average analyses of calcined magnesite at their four works are advertised by the Veitsch Company in their 1907 catalogue as follows:—

	Veitsch	Breitenau	Eichberg	Trieberg
MgO	88·22	87·89	85·86	85·91
CaO	0·87	2·77	3·00	4·51
Mn_2O_3	0·59	0·87	1·10	—
Fe_2O_3	7·07	5·47	5·29	6·83
Al_2O_3	0·86	0·69	0·10	1·44
SiO_2	2·35	2·00	5·06	0·63
	99·96	99·69	100·41	99·32

These analyses are, I understand, intended to be of the deadburned product as marketed after careful selection, but I have never seen a certified analysis of Veitsch magnesite in bulk so good as that given. We have specimens of that deadburned product, of which I am able to show micro-sections. These will be referred to again later, but from a first examination it is evident what a uniform mineral is able to be obtained with one burning from stone that requires so much careful treatment. That company has the advantage that the mines are under their own control and are alongside the works in which the refractory products are made, thus enabling the closest connection to exist between the quarrying and the manufacturing management. That is all the more reason why we should pay particular attention to all that we can learn about their products.

The specific gravity of the raw magnesite varies from 2·63 to 3·1, that of the oxide is 3·2, and of the deadburned product 3·545. When made into bricks, those of standard size of $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ in. (100 cubic inches) weigh 87·5 cwts. per thousand.

4.—*Claims for Austrian Magnesite.*

I believe it will be of interest if I give the following extract from an article by Professor H. Wedding[5]:—

In the Alps of Styria three kinds of magnesite are found:—*Pinolite*, which on account of the argillaceous earth can only be used as building material; *amorphous magnesite* mixed to a great extent with serpentine, and therefore used for making artificial stone; and thirdly, *magnesite spar*, resembling in its outward appearance spathic ironstone with lamellar grain, and of a yellowwhitish to light yellow colour. This last kind of magnesite is the only one that can be used as basic furnace lining.

The trifling contents of lime, alumina and sesquioxide of iron are too insignificant to cause fusing or sintering of the brick; but on the other hand they produce the desired condensation, and a slight contraction of the several parts, which is undoubtedly necessary to produce a basic lining of the highest refractory quality able to resist all mechanical influences in the furnace. It is this contraction which is the marked advantage of Spæter magnesite products as compared to most of the other magnesites which are devoid of this feature, and experiments made in order to produce this contraction by an addition of other substances have shown that artificial mixtures can in no way equal the one made by Nature in Styria.

The sorting done by hand ensures the utmost purity of Spæter magnesite, and consequently the highest refractory quality.

No foreign matter is added in making the brick. The refractory character of these bricks made under pressure of 300 tons remains therefore just as unaltered as that of pure calcined magnesite. Like the latter the bricks are subject for a long time to the utmost white heat. Special bricks and blocks are fired as much as two and three times with a view to obtaining perfect homogeneity and uniformity.

I shall also give two more excerpts from the 1893 catalogue of the Veitsch Company:—

Not more successful than the use of dolomite have been the efforts to use crypto-crystalline chalk-like hydro-magnesite from Mantudi on the Greek island of Eubœa, or from Frankenstein, for linings for basic open-hearth furnaces. Both are specially well adapted for chemical purposes on account of their being so rich in carbonic acid and poor in metallic oxides, but they do not possess any qualities whatever for binding or fritting, and consequently cannot be made to "set" under heat, and therefore do not offer sufficient resistance to mechanical influences when used by themselves. Attempts have been made to add the necessary binding materials, but they have always resulted in detracting from the refractory qualities of the material, to such an extent as to make the mass unsatisfactory for modern refining apparatus.

Quite different from the above mentioned material, and possessing all their lacking qualities, is the massive crystalline carbonate of magnesia of Styria.[6]

Uniformly intermingled with the carbonate of magnesia in our magnesite is a certain definite amount of carbonate of protoxide of iron, which gives to the Styrian magnesite a quality lacking in the Greek and Silesian magnesite, being able to frit and incinerate at a high temperature without melting, a property that the furnacemen in the United States call "setting," when the calcined material is placed in the furnace lining and subjected to considerable heat. When our magnesite has been thus "set" it is very considerably increased in density and retains its volume without further expansion or contraction in varying temperatures to a remarkable extent.[5]

In other words, it has become a definite oxide mineral in the true sense of the word "mineral."

The average composition of the Veitsch magnesite according to analyses made regularly from samples drawn with care from the different working places is as follows:—

	1.	2.	3.	4.	5.	6.
Magnesia (MgO)...	77·49	81·88	85·34	81·66	85·93	87·39
Lime (CaO)... ...	4·89	5·02	3·31	2·78	4·01	3·10
Iron (Fe_2O_3) ...	—	—	6·85	7·39	—	8·29
Alumina (Al_2O_3)...	15·92	11·35	0·79	0·59	8·85	—
Silica (SiO_2)... ...	1·70	1·75	3·71	7·58	1·21	1·22
	100·00	100·00	100·00	100·00	100·00	100·00

The deadburned magnesite produced from the material taken from the six places of working and mixed together has an average composition approximately as follows:—

MgO	85·30
CaO	1·75
Fe_2O_3	7·79
Al_2O_3	0·82
SiO_2	3·40
	99·06

From this it can be seen that the percentage of lime in our deadburned magnesite is considerably lower than the analyses of the crude material show.

The quality and volume of the deadburned mineral, for use in the building of basic furnaces, is considerably increased through the reduction of the lime, and this is founded on the fact that oxide of calcium, when cooling rapidly, takes up moisture from the atmosphere and changes into hydroxide of calcium, which quickly crumbles into dust and is in this state almost completely removed in the work of sifting and sorting.

The analyses given in this excerpt of 1893 differ from those given in Part III above, which are from the 1907 catalogue, and in so far as the latter may be taken as correctly stated, they can be supposed to indicate the line of progress in the elimination and regulating of the impurities. Compare, however, the analysis of the magnesite tuyere given later.

These quotations are quite good advertising from the point of view of the Veitsch Company, but while there is much that deserves our serious consideration, there is no doubt that some of the statements are entirely unwarranted. In the first place we know that with suitable treatment Greek, Indian, Italian and Canadian magnesites can be fritted and moulded into bricks that do bear comparison with Austrian bricks, whatever secondary rank they have so far taken.

Secondly, there is no doubt that we can bring about from raw magnesites that are practically microstructureless an approximation to all the large microstructures that are recognisable in the recrystallized deadburned magnesites of Austria. When the latter are being calcined they are amorphous when the CO_2 is being driven off, and it is only with sufficiency of heat treatment that the oxide crystallizes.

Mr. W. H. Croft, President of the Harbison Walker Company of Pittsburg, states that the difficulty of thoroughly calcining "this white amorphous magnesite makes its use as a refractory impracticable,"[6] but I am quite certain that it is not only possible to bring about the recrystallization of the oxide economically, but that it has already been done on a considerable scale. This I will refer to when considering the Greek and Indian deposits later.

5.—*Austrian Magnesite Bricks.*

Other claims that have been put forward for the Austrian magnesite and bricks are undoubtedly right. These bricks have greater resistance to mechanical stresses in modern furnace practice than any bricks that have so far been made in large quantities from other magnesite. We know ourselves that the product obtained from the Veitsch magnesite is peculiarly suited for the manufacture of refractory bricks, and it is right to consider how far we can account for that high quality by comparison of the analyses given, with those of other magnesite deposits in other countries. However, too great consideration cannot be given to the average analysis, as I can give that of a brick purchased from Austria by Messrs. Wm. Beardmore & Co., Ltd., before the war, which after 2½ years' constant use in a forge furnace in a reducing atmosphere with a temperature rising to 1,500° C. was still thoroughly sound, and which analysis was made since the brick was taken from the furnace, with the following result:—

MgO	79·34	
CaO	6·40	
Mn_2O_3	Nil	
Fe_2O_3	8·00	Density – 3·37
Al_2O_3	1·50	
SiO_2	4·65	
Loss	0·20	
	100·09	

Two micro-photographs of this brick are given, one of these, taken at right angles to the other, being composed very largely of white massive crystalline particles. This lighter section was taken from a part of the brick where there was decidedly white crystal growth proceeding. It is not known whether that light coloured part was towards the heat or further from it, but undoubtedly the dark-coloured brick was becoming white, and the micro-sections show that most clearly (see Plates X and XI, Figs. 2 and 3). This change of colour is common to all magnesite bricks, notably to Greek, and the change can

leave the bricks composed of a loose porous mass of amorphous particles or of a dense compact mass of hard crystals, depending on the heat applied and the atmospheric conditions.

It is evident that the analysis of this brick is very different from what is commonly understood to be the average analysis of good bricks, but 2½ years' use in the wall of a furnace does not leave the bricks owing much to the user, and he can have little to say against it. If there can be this variation of average analysis by weight, what are the factors requiring most consideration?

Even a cursory examination shows that the Veitsch Magnesite Company's bricks are composed of great uniformity of particle and texture. There is variation of grain, as must be the case with material from all milling plants. But the mass is exceedingly homogeneous as ground masses go. When examined in micro-section they have a more uniformly crystalline structure than any other bricks I know of. In the meantime I only ask you to notice the remarkable regularity of subdivision of particle. Each of these particles is not more than one-eighth of an inch in diameter, and within its circumference it can hold 150—180 sub-divisions (Pl. X and XI, Fig. 5). This formation runs through most magnesites that are well prepared, and is evidence that the mineral is in the crystalline state. With regard to Beardmore's brick, there are several occurrences of a dull green crystal which reminds me of certain pyroxenes and chlorite minerals. It is here that the microscope is of so much advantage, telling us what the minerals are that are being formed. A trained petrologist on examination of any of these sections can say at once what these mineral impurities are, and with such guidance you very soon learn to distinguish between them. One naturally imagines that these bricks can only be produced from a mineral that before grinding was of high specific gravity, the particles of which were not only of a very uniform chemical composition, but were combined in crystalline particles composed of smaller crystals difficult to hydrate even when ground into the finest powder state. We have therefore to consider how that has been attained with raw magnesite that requires so much dressing, and how it will be attainable in this country, using as we do the amorphous raw magnesites of Greece and India.

6.—*Magnesia (MgO).*

It can be taken as a basic fact that the magnesia (MgO) in all magnesite minerals is essentially the same no matter where the magnesite comes from, and that if any two magnesites are recognisably distinct, that distinction is only temporary

and may be eliminated by careful treatment. Nature made some beds of raw magnesite ($MgCO_3$) in crystals so minute that they cannot be distinguished by the microscope, and the Austrian and other beds distinctly of massive crystals because of the peculiar atmospheric conditions obtaining at the time of formation. All of these have definite modes of formation geologically; the crypto-crystalline raw magnesite being generally recognisable as of a spherical structure, while some of the beds of the massive crystalline raw magnesite have cubic structures, suggesting a mode of deposition very different from the former. But it would be no more unlikely that all beds were at one time of massive crystals than that all were at another time amorphous—Nature taking it into her head to change only some of them—and having no more difficulty in crystal growth, given the necessary atmospheric and other conditions, than she would have elsewhere and under different conditions in breaking them up into the crypto-crystalline state. All of these are amorphous when the carbon dioxide has passed off. The main questions that concern us about the oxide are: (1) how best to ensure that we can in our factories economically take the place of Nature in making amorphous magnesia grow into crystalline magnesia, and how best we can retain the oxide in that state under furnace conditions, the larger crystals held together as they are in powder or in brick form by the magma of the impurities, and (2) whether any of the impurities present in the magnesite affect these minute crystals deleteriously, and whether there should be the elimination of some and the addition of other impurities so as to make the magma best answer our needs.

These are questions best considered as a whole, and I propose first to refer to the magnesite deposits of Greece and India and elsewhere from which we draw our supplies.

7.—*Magnesite from Greece, India, Canada, and elsewhere.*

The largest supply of amorphous magnesite comes from Greece, and the best mines in that country are situated in the island of Eubœa, owned by the Anglo-Greek Magnesite Co., Ltd., of London. As in the case of the Austrian magnesite supply, I think it will be sufficient if we consider the quality of the supplies of amorphous magnesite from one firm and that of the largest supplier, as this should answer all the main questions about the quality of this product of finely crystalline magnesite in comparison with the massive crystalline quality.

I have been fortunate in getting from the Anglo-Greek Co. some photographs of the country and of the deposits, which

will best introduce the subject. The photographs shown are as follows:—

(*a*) General view of the hill country (Pl. XIII).

(*b*) Hill of magnesite being quarried (Pl. XIV).

(*c*) Face of magnesite quarry showing entrance to shaft Pl. XV).

(*d*) Entrance to shaft near at hand showing the magnesite in a massive face (Pl. XVI).

(*e*) Openwork quarry showing earth burden and contorted appearance of the magnesite there (Pl. XVII).

(*f*) Another quarry showing the magnesite leaving the quarry by rail (Pl. XVIII).

(*g*) View of the port of St. Johns with calcining plant (Pl. XIX).

(*h*) Map of the deposits, the principal of which are the Galataki group; Trupi, Kakavos, Moraitis, Strongyli, Archangelos, Ardralee, Hortocope and Pefteli, from all of which the magnesite is transported and shipped at St. John, as also is the magnesite from the Limni deposits; the Mantudi mines, connected with the Yerorevma and Plakaries mines, 2½ miles distant, the magnesite from which is transported by aerial railway to the port of Kymassi; and Daphnopotamos, Levidakia, Atlantos, Stavros, Maccas, Haghia-Triti, Goudsee, Kalamaki, Alonaki, Aspri Vrisi, Xeropotamos and Papades, all of which is shipped at Pyli; and the Afrati Mines, the output of which is shipped at Chalcis (Pl. XX).

In addition to the works at St. John the Anglo-Greek Co. have works of similar dimensions at several other places named.[7]

One interesting fact is that the deposits on the west side of the island dip to the north or east, while those on the east side dip to the north or west in nearly all cases. This leads us to imagine that there must have been a hiatus in the centre of the island at the time of transformation. In some quarries the bed rocks are of soft or hard serpentine or talc, sometimes with two or three inches of pure calcite in powder between the magnesite and the serpentine. The side walls are at times of hard serpentine, both the magnesite and the serpentine walls having hard clear-cut faces. In another instance the magnesite vein ends in the side of a stream on the other side of which there is no appearance of magnesite at that point. It is present sometimes in veins 5 ft. to 10 ft. broad, and at other times in very large deposits, as at Limni, Mantudi and Haghia-

Triti. At several of the largest deposits the magnesite is of a remarkably white dense appearance and very free from impurities.

The stone as mined is carefully selected and a very uniform quality is shipped, but I believe from examination of the cargoes we receive that greater elimination of impurity can be attained if that turns out to be necessary. Much of the rock is exceedingly pure, as the following analyses,[8] given alongside an average analysis, will show:—

	Average Analyses	Specimen 36A	36B	Average of A and B
Magnesia	90·67	92·21	95·03	93·63
Lime	3·02	1·51	3·52	2·52
Protoxide of Iron	None	0·04	0·07	0·5
Peroxide of Iron	·71	0·04	0·06	0·5
Alumina	·69	2·04	0·91	1·47
Oxide of Manganese ...	None	None	None	None
Sulphuric Acid	·08	0·16	0·20	0 18
Siliceous matter	4·20	4·00	0·21	2·11
Total	99·37	100·00	100·00	100 00

As it is, one sees that this magnesite is considerably purer than the Austrian magnesite, and naturally the question is asked why further selection should be required. This takes us again to the question of impurities, and now to the *kind* of impurities; but before dealing with that I wish to point out how the impurities in the Greek magnesite are present, and how they attack the purest parts of the stone.

9.—*Impurities.*

If reference is made to the photographs of these Greek quarries there will be noticed the earth burden on top of the deposits and the fractures showing in the magnesite beds, allowing surface water to carry impurities with it. Not much of these affect this particular question, however, as detritus is removed in the handling and selecting of the rock pieces; but it is in this way that the iron and alumina, present in the magnesite, have appeared, taking foothold where they have been able to get it, and becoming gradually altered in the course of many years into hard crusts. This is a most irregular distribution of the iron and alumina; much more irregular than the presence of lime, which to the extent of nearly 1 per cent. runs uniformly through most of the raw magnesite. Otherwise the lime is present as dolomite, mainly through irregular intrusions of dolomite, but possibly also because of the borderland of the magnesite and dolomite beds having been entered

unnoticed in the course of mining and quarrying. In altered beds like magnesite there is always a transition zone more or less of the one mineral or of the other. The silica is present as quartz or as a constituent of talc, pseudomorphs of talc, or serpentine, or other magnesian silicates. The bed-rock being often of this mineral, seems to suggest that the alteration came from above, only affecting the rocks in sections and sometimes passing over a neighbouring hillside with remarkably little alteration, the depth of the alteration being easily ascertained. It is partly owing to this irregular distribution of the mineral impurities that the finely crystalline magnesite is so difficult to calcine hard enough to deadburn the mineral throughout its entire bulk.

10.—*Impurities of Canadian Magnesite.*

This irregularity of deposit is much more evident in the Canadian magnesites. An interesting publication has been issued by the Canada Department of Mines[9] in which the following mineral impurities of the Grenville deposits are mentioned: Dolomite, diopside, phlogopite, quartz, talc, sphalerite, magnesite and graphite, and short descriptive notes are given about each to enable easy recognition. Notes are also given about the determination of the lime-content of magnesite and dolomite which I shall quote:—

Cream-white, medium to fine-grained glistening magnesite, usually contains less than 7 per cent. CaO.

Snow-white, medium or fine-grained glistening magnesite, usually contains less than 11 per cent. CaO.

Milk-white, medium or fine-grained glistening magnesite, usually contains less than 12 per cent. CaO.

Grey magnesite is generally more highly dolomitic than either snow-white, cream-white or milk-white, but there are a few striking exceptions to this rule.

Dull white material is dolomite and contains approximately 30 per cent. CaO.

Coarsely crystalline material (that is, material exhibiting cleavage faces generally greater than one-fourth inch in diameter) is usually dolomite and contains approximately 30 per cent. CaO.

11.—*Consideration of the Nature of the Impurities.*

These descriptions of the different qualities of Canadian magnesites do not correspond with the appearance of the magnesite lumps we get from Greece, India and elsewhere; but

the latter can be described on similar lines to enable easy recognition of the various qualities. With such a scale before us I am sure that the selection of the magnesite rocks containing percentages of lime greater than usual could be more rigorously carried out by our labourers, as they could certainly recognise in these descriptions single pieces of such rock in the shipments we receive, and their elimination should take us in the right direction.

Similarly we can recognise the rocks containing the greater percentage of silica. And I am positive that such a selection could make the Greek product compare much more favourably with the Austrian for silica and lime content. With that possible we can then add whatever impurity would be better.

Before proceeding further I would like to consider if there are any reasons able to be defined for the silica-lime impurities being considered of less value than the iron-alumina impurities. To do this, in the first place I propose to compare analyses of known magnesite bricks of recognised standard, and particularly their impurities, excluding the basic magnesia and lime, and treating the silica, alumina and iron impurities by themselves, showing their total, in ratio to the total magnesia and lime, and also to consider their volume in relation to the volumes of magnesia and lime present. Following on that we shall consider the melting points of the mineral compounds formed.

The magnesite analyses to be considered will be the following:—

(1) Three analyses communicated by Messrs. Gilbertson in February, 1917: (1) Continental, (2) English, and (3) American. These were referred to as first, third and second quality respectively.

(4) Spæter's magnesite as advertised by them as at their Veitsch mines.

(5) Analysis of tuyere from Austria reported on by Messrs. Wallace & Clark of Glasgow, in June, 1916.

(6) Analysis of Austrian brick after use in Messrs. Beardmore's furnace: analysis supplied by them.

(7) Analysis of Canadian magnesite brick reported by Canada Department of Mines as made from Grenville magnesite.

(8) Analysis of Norwegian magnesite brick by Messrs. Wallace & Clark in 1916.

(9) Analysis of Norwegian magnesite brick supplied by Messrs. Ridge Beedle & Co.

(10) Analysis of Greek magnesite brick as pure as possible.

(11) Calculated analysis of Greek magnesite brick with addition of 3 per cent. ferric oxide.

(12) Calculated analysis of Greek magnesite brick with addition of 6 per cent. ferric oxide.

(13) Calculated analysis of Greek magnesite brick with addition of 9 per cent. ferric oxide.

I.—Actual Analyses of Magnesites.

	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2	Mn_3O_4	Total		Per cen Impuriti
Gilbertson Bricks: ...									
Foreign	86·13	2·40	6·45	2·55	2·20	—	99·73	1.	11·2
English	85·44	3·50	4·49	2·01	4·40	—	99·84	2.	10·9
American ...	86·40	2·40	5·52	1·38	4·80		100·50	3.	11·7
Veitsch Brick ...	88·22	0·87	7·07	0·86	2·35	0·59	99·96	4.	10·8
Austrian Tuyere ...	83·71	4·05	8·03	1·50	2·02	0·56	99·87	5.	12·1
Beardmore Brick ...	79·34	6·40	8·00	1·50	4·65	—	99·89	6.	14·3
Canadian Brick ...	71·75	8·70	6·67	2·98	10·26	—	100·36	7.	19·9
Norwegian Brick (*a*)	62·93	3·70	2·50	8·95	21·75	—	99·83	8.	33·2
,, ,, (*b*)	71·60	2·30	6·00	4·50	15·40	—	99·80	9.	25·9

II.—Calculated Analyses for Comparison.

Greek Bricks:									
Pure	90·00	4·00	0·50	1·00	4·50	—	100·00	10.	6·0
3 per cent. Fe_2O_3 ...	87·38	3·88	3·40	0·97	4·37	—	100·00	11.	8·7
6 per cent Fe_2O_3 ...	84·91	3·78	6·13	0·94	4·24	—	100·00	12.	11·3
9 per cent. Fe_2O_3 ...	82·57	3·67	8·72	0·92	4·12	—	100·00	13.	13·7

III.—Approximate Equivalent Volumes of the Constituents considered as Oxides calculated on Specific Gravity given.

(Approximate cubic centimetres of the various oxides in 100 grams of the Magnesites.)

	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2	Mn_3O_4	Total c.c.	Per cent. Impurities
Sp. gr.	3·67	2·9	5·12	3·85	2·32			
Gilbertson Bricks: ...								
Foreign	23·47	0·83	1·26	0·66	0·95	—	28·20	10·28
English	23·28	1·21	0·87	0·52	1·89	—	27·85	12·07
American ...	23·54	0·82	1·08	0·36	2·17	—	27·95	12·73
Veitsch Brick	24·04	0·30	1·38	0·22	1·01	0·11	27·11	10·22
Austrian Tuyere ...	22·81	1·39	1·59	0·39	0·57	0·11	28·19	10·61
Beardmore Brick ...	21·62	2·20	1·56	0·39	2·00	—	27·85	14·47
Canadian Brick ...	19·53	3·00	1·30	0·77	4·42	—	29·20	22·84
Norwegian Brick (*a*)	17·15	1·27	0·49	2·32	9·50	—	30·73	40·06
,, ,, (*b*)	19·51	0·79	1·17	1·17	6·73	—	29·37	30·81
Greek Bricks:								
Pure	24·50	1·38	0·10	0·26	1·73	—	28·26	8·42
3 per cent. Fe_2O_3 ...	23·68	1·38	0·68	0·26	1·88	—	28·02	10·56
6 per cent. Fe_2O_3 ...	22·87	1·38	1·27	0·26	1·82	—	27·80	12·77
9 per cent. Fe_2O_3 ...	22·05	1·38	1·85	0·26	1·77	—	27·56	14·98

IV.—Stöichiometric Weights of the Constituents considered as Oxides with the weights of the total impurities calculated as 100 grams, showing the weights of the Magnesites that would be required to hold 100 grams of these impurities and the ratio between the weight of the total impurities and the Lime and Magnesia present.

	Impurities					Ratio of Impurities to Mass by Weight		
	Fe_2O_3	Al_2O_3	SiO_2	Mn_3O_4	Total	CaO	MgO	Total
Gilbertson Bricks:								
Foreign	57·6	22·8	19·6	—	100	21	769	890
English	41·2	18·4	40·4	—	100	32	873	1,005
American	47·2	11·8	41·0	—	100	20	738	858
Veitsch Brick	65·0	7·9	21·6	5·5	100	8	811	919
Austrian Tuyere ...	66·3	12·4	16·7	4·6	100	33	691	824
Beardmore Brick ...	56·5	10·6	32·9	—	100	44	552	707
Canadian Brick ...	53·5	15·0	51·5	—	100	43	359	503
Norwegian Brick (*a*)...	7·5	26·9	65·6	—	100	11	189	300
,, (*b*)...	23·2	17·4	59·4	—	100	8	276	385
Greek Bricks:								
Pure	8·3	16·7	75·0	—	100	66	1,500	1,666
3 per cent. Fe_2O_3 ...	38·9	11·1	50·0	—	100	44	997	1,141
6 per cent. Fe_2O_3 ...	54·2	8·3	37·5	—	100	33	750	883
9 per cent. Fe_2O_3 ...	63·4	6·7	29·9	—	100	26	600	726

V.—Equivalent Volumes of the Constituents as Oxides with the Volumes of the total impurities calculated as equivalent to 100 cubic centimetres, showing the total volumes of the Magnesites that would be required to hold such a volume of the impurities and the ratio of the volume of the total impurities to the volume of the Lime and the Magnesia present. (Omitting decimals.)

	Impurities					Ratio of Impurities to Mass by Volume		
	Fe_2O_3	Al_2O_3	SiO_2	Mn_3O_4	Total	CaO	MgO	Total
	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Gilbertson Bricks:								
Foreign	43	22	33	—	100	28	809	937
English	25	15	58	—	100	36	690	828
American	20	10	69	—	100	22	655	778
Veitsch Brick ...	49	8	37	4	100	10	866	978
Austrian Tuyere ...	53	13	30	4	100	46	762	909
Beardmore Brick ...	38	9	51	—	100	54	536	691
Canadian Brick ...	19	11	69	—	100	44	292	437
Norwegian Brick (*a*)	3	18	78	—	100	10	139	249
,, ,, (*b*)	12	12	74	—	100	8	215	323
Greek Bricks:								
Pure	4	11	84	—	100	60	1,075	1,235
3 per cent. Fe_2O_3 ...	23	9	67	—	100	47	853	1,001
6 per cent. Fe_2O_3 ...	36	7	56	—	100	38	707	846
9 per cent. Fe_2O_3 ...	46	6	47	—	100	34	608	742

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VI.—Comparison of impurities present, taken from Tables IV and V.

Ratio of Impurities to Mass by Weight	Fe_2O_3	Al_2O_3	SiO_2	Mn_3O_4	Magnesite No.	Fe_2O_3	Al_2O_3	SiO_2	Mn_3O_4	Ratio of Impurities to Mass by Vol.
1 to 8·9	57	22	19	—	1	43	22	23	—	1 to 9·4
1 to 10·1	41	18	40	—	2	25	15	58	—	1 to 8·3
1 to 8·6	47	11	41	—	3	20	10	69	—	1 to 7·8
1 to 9·2	65	7	21	5	4	49	8	37	4	1 to 9·8
1 to 8·2	66	12	16	4	5	53	13	30	4	1 to 9·1
1 to 9·1	55	10	32	—	6	38	9	51	—	1 to 6·9
1 to 5·0	33	14	51	—	7	19	11	69	—	1 to 4·4
1 to 3·0	7	26	65	—	8	3	18	78	—	1 to 2·5
1 to 3·8	23	17	59	—	9	12	12	74	—	1 to 3·2
1 to 16·7	8	16	75	—	10	4	11	84	—	1 to 12·3
1 to 11·4	38	11	50	—	11	23	9	67	—	1 to 10·1
1 to 8·8	54	8	37	—	12	36	7	56	—	1 to 8·5
1 to 6·7	63	6	29	—	13	46	6	47	—	1 to 7·4

VII.—Comparison of ratios of impurities and Lime and Magnesia.

Ratio of Impurities to Mass by Weight	Impurities	CaO	MgO	Total	Magnesite No.	Impurities	CaO	MgO	Total	Ratio of Impurities to Mass by Volume
1 to 8·9	100	21	769	890	1	100	28	809	937	1 to 9·4
1 to 10·1	100	32	873	1,005	2	100	36	690	828	1 to 8·2
1 to 8·6	100	20	738	858	3	100	22	655	778	1 to 7·8
1 to 9·2	100	8	811	919	4	100	10	866	978	1 to 9·8
1 to 8·2	100	33	691	824	5	100	46	762	909	1 to 9·1
1 to 7·1	100	44	552	707	6	100	54	536	691	1 to 6·9
1 to 5·0	100	43	359	503	7	100	44	292	437	1 to 4·4
1 to 3·0	100	11	189	300	8	100	10	139	249	1 to 2·5
1 to 3·8	100	8	276	385	9	100	8	215	323	1 to 3·2
1 to 16·7	100	66	1,500	1,666	10	100	60	1,075	1,124	1 to 12·3
1 to 11·4	100	44	997	1,141	11	100	47	853	1,001	1 to 10·0
1 to 8·8	100	33	750	883	12	100	38	707	846	1 to 8·5
1 to 7·5	100	26	600	726	13	100	34	608	742	1 to 7·4

12.—*Comparison of Austrian and British-made Magnesite Bricks*

To take two instances from the foregoing figures, we have the Gilbertson foreign brick containing 11·20 per cent. of impurities by weight and 10·28 per cent. by volume; and the Gilbertson English brick containing 10·90 per cent. impurities by weight and 12·07 per cent. by volume. The analyses are not very dissimilar. It seems to be almost in its favour that the English brick holds 100 grams of impurities in 1,005 grams of mass weight, while the foreign brick holds that quantity in 890 grams of mass weight. But if you turn to Table V it is seen that the English brick holds 100 c.c. of impurities in 828 c.c. of mass, while the foreign brick holds that volume of impurities in 937 c.c. of mass.

One would expect the Gilbertson brick to compare very closely with the Beardmore brick, but if anything to be better, as the volume required to hold the 100 c.c. of impurities is 937 c.c. against 691 c.c. The smaller volume in the case of the Beardmore brick would let the volume attack of the impurities act more quickly, but that is subject to the proviso that the impurities present would act the same way in each case.

The addition of 3 per cent. 6 per cent. or 9 per cent. of Fe_2O_3 to the Greek magnesite would give average analyses closely corresponding to some of these actual analyses; but one should find out how mixtures of the oxides of each of these analyses might be expected to act towards pure MgO in lump and also in a fine state of division, particularly in the presence of known percentages of lime. The points of incipient fusion of cones made with compositions exactly those of the impurities in bricks 1 to 7 and 10 to 13 in Table IV are as follows:—

TABLE VIIA.

	Impurities					Point of incipient fusion	
	Fe_2O_3	Al_2O_3	SiO_2	Mn_3O_4	Total	Cone	
Gilbertson Bricks:							
Foreign	57·6	22·8	19·6	—	100	01a	1,080° C.
English	41·2	18·4	40·4	—	100	03a	1,040° C.
American ...	47·2	11·8	41·0	—	100	05a	1,000° C.
Veitsch Brick ...	65·0	7·9	21·6	5·5	100	1a	1,100° C.
Austrian Tuyere ...	66·3	12·4	16·7	4·6	100	1a—2a	1,110° C.
Beardmore Brick ...	56·5	10·6	32·9	—	100	06a—05a	990° C.
Canadian Brick ...	53·5	15·0	51·5	—	100	04a	1,020° C.
Greek Bricks:							
Pure	8·3	16·7	75·0	—	100	14—15	1,422° C.
3 per cent. Fe_2O_3 ...	38·9	11·1	50·0	—	100	04a	1,020° C.
6 per cent. Fe_2O_3 ...	54·2	8·3	37·5	—	100	07a—06a	970° C.
9 per cent. Fe_2O_3 ...	63·4	6·7	29·9	—	100	04a	1,020° C.

It is remarkable that mixtures of these oxides differing so widely the one mixture from the other should have uniform temperatures of incipient fusion. The important questions arising are: (1) which of these from practical experience gives the best result in the finished brick, and in the meantime in connection with the immediate question under review, (2) in conjunction with the lime (CaO) present in the magnesite, what kind of penetrating magma will 57 per cent. Fe_2O_3, 22 per cent. Al_2O_3, and 19 per cent. SiO_2 give, and again 41 per cent. Fe_2O_3, 18 per cent. Al_2O_3 and 40 per cent. SiO_2? These are the percentages by weight.

13.—*Action of Mineral Impurities on Magnesite.*

As I said earlier, it does not do to place too much stress on average chemical analysis by weight of magnesite bricks, as their physical factors enter so much into the question of their

value. For instance, not all the impurities form what one can call the magma in magnesite bricks, though I have ascertained that the bulk of the magma actually does correspond approximately to the average analysis of these impurities. A certain percentage of the balance form distinct compounds with the lime present. Others of them form mineral compounds closely corresponding to well known minerals found in Nature, which do not lose their mineral characteristics without very prolonged firing. Even then they do not lose their position, as a magma may be expected to do, except in so much as they affect the surrounding particles of the magnesite mineral. It is only after prolonged use that the original characteristics of a few of the more refractory of the mineral impurities in British magnesite bricks definitely vanish.

14.—*Weight and Volumes.*

It is evident, however, from comparison of Tables VI and VII, taken in conjunction with the actual reports on the bricks whose analyses are given, that the question of percentage by volume sometimes suggests reasons for the comparative worth of the brick. The following Table VIII and Fig. 1 give a direct comparison of the molecular volumes and the specific volumes occupied by 100 grams of the oxides that interest brickmakers, and the latter will, I think, better still bring out this question of the comparative volumes occupied by the constituents of magnesite bricks considered as oxides, and doing so will answer some of the questions that meet us in connection with our manufactures.

VIII.—Molecular Weights and Volumes of the Oxides constituting Magnesite and other Bricks.[11]

	Molecular Weight	Specific Gravity	Molecular Volume	Specific Weight Grams.		Specific Volume c.c.
Silica (SiO_2) as quartz	60·4	2·65	22·8	100	=	37·75
,, ,, as (*a*) cristobalite	60·4	2·32	26·03	100	=	43·69
,, ,, as (*b*) tridymite	60·4	2·30	26·26	100	=	43·47
Lime (CaO)	56·0	2·9	19·31	100	=	34·48
Magnesia (MgO)[1]	40·36	3·01	13·41	100	=	33·225
,, (MgO)[2]	40·36	3·67	11·00	100	=	27·255
Alumina (Al_2O_3)	102·2	3·85	26·546	100	=	25·98
Manganese Protoxide (MnO)...	70·8	5·18	13·67	100	=	19·31
Ferric Oxide (Fe_2O_3)	160·0	5·12	31·25	100	=	19·53
Manganese Oxide (Mn_3O_4) ...	228·4	4·722	48·37	100	=	21·18
Chromic Oxide (Cr_2O_3)... ...	152·2	5·21	29·215	100	=	19·195
Zirconia (ZrO_2)	122·5	5·71	21·45	100	=	17·51
Ferrous Oxide (FeO)[3]	72·0	6·23	11·56	100	=	16·06
Potash (K_2O)[3]	94·0	0·859	109·4	100	=	116·4
Soda (Na_2O)[3]	52·0	0·9723	53·5	100	=	102·9
Phosphoric Oxide (P_2O_5) ...	142·0	1·85	76·7	100	=	54·06

1 Fired at ordinary temperatures.
2 Electrically fused.
3 Approximately correct.

An indication is given on Fig. 1 of the difference in molecular volume, and the specific volume of 100 grams, of mineral in the case of silica and MgO, at their points of maximum and minimum specific gravity. In the case of silica the lesser volume in each case is that of quartz, and the greater is that of tridymite, but in particular I desire you to notice the greater volume of silica and lime and the lesser volumes of iron and alumina.

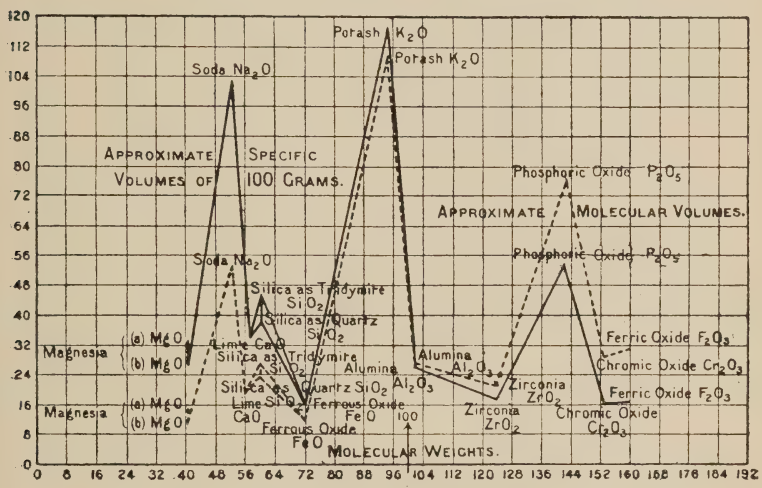

Fig 1.

15.—*Magnesia and Lime Compounds.*

It is even more interesting to consider the volumes occupied by the respective magnesia and lime compounds and the various mineral impurities recognised by microscopic examination to be present in magnesite bricks. Table IX and Diagram 2 give closely related minerals, and there are added for comparison several other minerals more commonly met among the basic mineral products such as Portland cement and basic slag.

IX.—MAGNESIA LIME MINERALS.

Average Stöichiometric Weight of Oxides present in the percentage analysis and the equivalent volumes and specific weights of 100 grams, based on the specific gravities of actual minerals, as given by Dana.

Mineral	Symbol	Av. Stöich. wt. of oxides present in % analysis	Spec. Gravity	Equivalent Vol.	Spec. vol. of 100 grams of material
Periclase	MgO	40·36	3·67	10·98	27·2
Forsterite	$2MgO.SiO_2$	48·80	3·21	15·05	30·8
Chrysolite	$2(MgFe)O.SiO_2$ ...	51·04	3·26	15·7	30·76
Tremolite	$CaO.3MgO.4SiO_2$ ...	53·67	3·0	17·7	33·00
Enstatite	$MgO.SiO_2$	54·25	3·2	16·77	30·91
Bronzite	$(MgFe)O.SiO_2$	54·82	3·3	16·54	30·2
Monticellite	$CaO.MgO.SiO_2$ ...	55·36	3·1	17·75	32·06
Diopside	$CaO.SiO_2.MgO.SiO_2$	58·08	3·2	18·2	31·3
Hypersthene ...	$FeO.SiO_2.3(MgO.SiO_2)$	58·36	3·45	17·32	29·7
Wollastonite ...	$CaO.SiO_2$	58·25	2·8	20·4	35·02
Pyrope	$3MgO.Al_2O_3.3SiO_2$ ...	71·30	3·7	19·48	27·3
Spinel	$MgO.Al_2O_3$	86·38	3·55	22·35	25·9
Magnesioferrite ...	$MgO.Fe_2O_3$	136·07	4·6	29·8	21·9

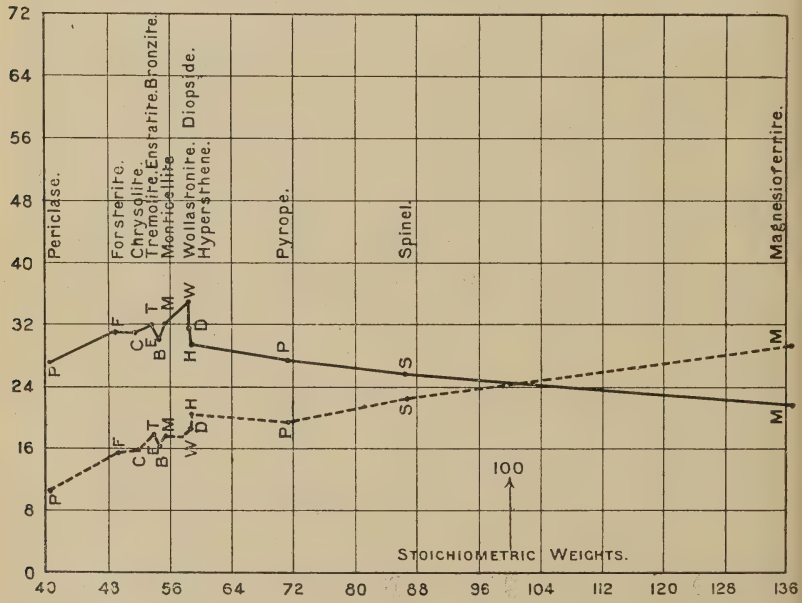

Fig. 2.

The molecular weights of minerals are based on the additions of the stöichiometric values of their chemical formula; but I believe that it is more interesting to consider in relation to other factors concerning the minerals such as the specific volume of 100 grams the average stöichiometric weights of the oxides present in the percentage analysis, the molecule of the mineral having that percentage analysis and the specific volume

of 100 grams derived by either *A* or *B* factors being exactly the same. In Table IX, therefore, I have given the average stöichiometric weight of the mineral compound arrived at from the percentage analysis and have calculated the specific volume from that factor, dividing it by the actually known specific gravity of the particular mineral, which specific gravity of the several qualities of any mineral varies according to the exact analysis. If one were to calculate from the atomic weight of the constituents of the mineral, that would require a very high molecular weight line in the diagram for that mineral. The following is my calculation in the case of tremolite ($CaO.3MgO.4SiO_2$):—

			Molecular weight	
SiO_2	...	57·7	60·4	34·85
MgO	...	28·9	40·36	11·66
CaO	...	13·4	56·0	7·50
		100·0		54·01

The specific gravity of tremolite of that particular analysis is given by Dana as 3·0 which would give a volume equivalent of 18 c.c., which is equivalent to a specific volume of 100 grams of material of 33·33 c.c.

For comparison of the molecular volume and the factors I have given derived from the stoichiometric weights of the oxides present in pyrope, I give the following:—

Molecular weight	402·0	Average stöichiometric weights of oxides present in Pyrope...	71·30
Specific gravity	3·7	Specific gravity	3·7
Molecular volume	108·7	Volume equivalent	19·48
Specific volume of 100 grams...	27·3	Specific volume of 100 grams...	27·3

Taking the volume line 31, it will be noticed in the first place that the lime compound wollastonite is above that line, and that the magnesia compounds forsterite and magnesioferrite are below. But this diagram is inapplicable in a consideration of the gross volume densities of the materials in working practice because no account is taken of the porosity, and this is a factor that magnesite brickmakers in particular must take note of. We must have no compound in our brick that tends towards porosity of brick or even of particle. The diagram is also inapplicable in a consideration of the gross volume densities of the mineral impurities as they will be found in the highly-fired magnesite brick owing to the alteration of the specific gravity that takes place in all these minerals at high temperatures. That some of the silicates of magnesia and other compounds in the magma of our bricks cause higher porosity locally than others do, we know definitely by microscopic examination of sections of the bricks under reflected light.

This is due to a difference of coefficient of expansion on heating, and further to a difference of coefficient of contraction on cooling. It would be interesting to have a report about these porosities on truly scientific lines showing the various porosities that are found in the various bricks, and how each affects the gross volume density of the bricks, the report accounting for the porosity being greater in some cases than in others. Some of the more minute porosities are due to gas occlusions.

I also wish to point out that 100 grams of magnesioferrite ($MgO.Fe_2O_3$) occupies less volume than 100 grams of periclase, and that 100 grams of hypersthene ($FeO.3MgO.4SiO_2$), diopside ($CaO.SiO_2.MgO.SiO_2$), forsterite ($2MgO.SiO_2$) or even spinel ($MgO.Al_2O_3$) among other compounds (particularly the lime compounds), each occupies greater volume than 100 grams of periclase. The volume of magnesioferrite also is less than that of what has been called β-magnesia, 100 grams of the two having the respective volumes of 19·5 c.c. and 27 c.c.

16.—*Melting Points of Magnesite Bricks.*

These tables and the two diagrams will perhaps suggest reasons on full consideration for the Austrian bricks having such greater longevity than the British-made Greek bricks in modern furnaces, and being able to a greater extent to be rebuilt into the furnaces under repair. On examining micro-photographs of bricks that have been fired at 1,750° C. there is much greater alteration of the magnesite particle noticeable in the Greek than in the Austrian brick (see Pl. XXIII and XXIV). The alterations of the particles of the Greek bricks are more noticeable than those of the Austrian, as these become so opaque. In the latter, too, the direct examination by the microscope brings out the light and shade of the reddish-brown colouring at places in a way that the microphotograph cannot do. Much of the white areas show the development in the Austrian brick of the white magnesia formation. With direct examination of the micro-section in the microscope it is easily possible to distinguish between that and the porosity of the section. The minute porosity in certain of the particles of Pl. XXIV, Fig. 2, is due to gas occlusions. These are representative specimens of Greek and Austrian bricks. In the former there is greater porosity between the particles, particularly in those that have most evidence of the growth of microstructure. Carried to the highest point that I have so far had done, viz.: 1,850° C., there is evidence in the Greek bricks of the segregation of impurity and weakness locally. At such places shock, such as the abrasion of slag, might well bring about rupture.

Magnesium (Mg) is an element with great affinity for oxygen,[12] and the oxide magnesia has such stability that nearly all other oxides would part with their oxygen at temperatures below the point of dissociation of oxygen from magnesia. That point of dissociation from oxygen is in the case of some metallic elements actually higher than the point of volatilization of the metal itself. Instances are iron, tin, manganese and lead. Lower than that temperature of dissociation of the oxygen from the oxide, however, would be the temperature of the attack of the oxide itself on the magnesia oxide. If the percentages of the oxide impurities are within certain clearly defined limits they form minerals with definite micro-structures. At the point of dissociation of the oxygen from the magnesia (at 2,500° C.) complete volatilization would take place. Owing to the presence of impurities in magnesite bricks their point of volatilization is about 1,800° to 2,000° C., depending on the time the bricks are exposed to those temperatures. Such temperatures are only experienced by that end of the brick exposed directly to the combustion zone and within a limited radius from the area of greatest furnace temperature. While the temperature at the arc in electric furnaces is 2,000° C. the temperature at the walls of the furnace is not greater than 1,800° C. These electric furnaces are about 5 feet square.

Another fact to be remembered is that borne out in electric furnace practice where the interaction between the carbon electrodes and the magnesia bottom seems to bring about volatilization of the magnesia from carbides that have been formed. This cindering of magnesia is sometimes noticed in the gas inlets of brick kilns where the flame impinges directly on the surface of the bricks. I have seen the magnesite bricks directly at these gas inlets not only having their surfaces affected, but having distinct evidence, to the extent of fully ½ in. of material, of volatilization having taken place. Without the presence of carbon, however, the temperature of dissociation of the oxygen from the magnesia being above furnace temperatures, it may be said that the melting point of magnesia is never fully reached, and all that can be stated definitely is that magnesite bricks subjected to increasing heat or to long continued high temperature assume certain microstructures depending on the purity of the magnesite or the proximity to the metal or slag or to the oxide dusts. It is possible to have a definite knowledge of the thermal history of magnesite bricks by the examination of the micro-sections prepared from the bricks at definite stages of firing. These disclose the growth of microstructure referred to above.

17.—*Conversion of Crystals.*

I am confident that what takes place in the conversion of the mineral from minute crystals into larger crystals is that with crystal growth we have intense concentration of mineral with increased density at that growth, and therefore porosity between the various growths. If we had these growths before the brick was moulded, or if we had that even to a certain extent, provided that we had the full conversion when the brick is being fired, I am confident there would not be this contraction proceeding in the steel furnace after manufacture. In silica bricks we experience conversion, but there the problem is to take into account the expansion. Here it is a much more trying matter when the conversion brings about increase of specific gravity with contraction in the mineral particle.

If there is expansion, as in the case of silica bricks, the joints of the brickwork are tightened and the metal, or the slag, or the oxide dust, does not attack more than the face exposed to the furnace, and cannot attack the jointing silica cement. But when there is contraction, as with magnesite bricks, the joints of the bricks at the ends immediately next to the furnace are attacked, and this assists in that end of brick being so altered in dimensions that a cleavage takes place between the contracted and uncontracted parts which is known as spalling.

18.—*The Magma.*

The magma of magnesite bricks is formed by the interaction of the mineral impurities present. If cones are prepared corresponding in percentage composition with that of impurity oxides present in any particular brick, and if these cones are fired to their point of incipient fusion, their micro-section and the micro-section of the brick itself laid on white paper appears to the eye to have approximately the same coloration. If Greek magnesite bricks are fired in an electric furnace many times at cone 30 the brown coloration disappears,[13] leaving a mass of pure white mineral, showing small segregations of impurity locally, and of microstructures very similar to those of Austrian bricks. The white mass on being again fired under the firing conditions (temperature and atmosphere) of manufacture, assumes its normal colour, but with a more even coloration throughout the mass, and of a slightly darker hue than it had originally.

In the Austrian bricks the magma interpenetrated each particle, acting as a catalyst and bringing about uniform microstructural changes in particles of similar dimensions. It

distributes itself throughout the entire 100 cubic inches of the standard square brick in a way that our magma does not do till the bricks with each presentation of a new face after spalling get the full heat and are converted into the larger crystal formation, when what often takes place is a frothing with great porosity. With the magma concentrated between the larger of the unconverted particles of our Greek magnesite bricks we have that magma at furnace temperatures more readily acting on the finest particles, and practically in a molten state holding larger particles which, as the greater heat reaches them, contract by conversion, which then takes place. If that conversion had already taken place before use there would be this magma of ours distributed throughout each particle, subject to the proviso that our particular magma can bring about the allotropic change at the kiln temperatures at our command, which is what I am inclined to doubt. The kind of silicates of magnesia that we have are bulky and highly viscous. It is said that with a melting point at 1,550° C. they at 100° C. higher are still almost immovable as a molten liquid. Perhaps it is more descriptive of them to say that they are stationary and only grow if their surrounding matter is able to form itself into a similar or closely corresponding mineral compound. It is for this reason that I think we must introduce ferrous oxide or manganese, which will make them readily penetrate the finest particles at convenient temperatures, and which must be present in a given percentage, the other impurities being also present in percentages whose maximum and minimum limit can be ascertained and stated. It is as a catalyst able to bring about an allotropic change at temperatures of 1,400° to 1,500° C. that in the first place these additions might be made; but they seem to have properties in conjunction with magnesia, forming definite mineral compounds of great stability under a wide range of the highest temperatures, and of greater density than the highest temperature formations of magnesia itself, and this warrants close examination into the properties of such compounds and also into the furnace standing powers of bricks made from them.

19.—*Production of the Magma.*

To understand the production of the magma in the bricks themselves we have to consider how these percentage impurities were held in the raw magnesite *before calcination.* To understand the sequence of interactions that take place we have to take into account the temperatures at which the various combinations will take place between the various oxides, and we have to consider what becomes of each of the original mineral

impurities in the sequence of change *during calcination.* Some of the particles of the mineral impurities can be traced stage by stage throughout the process of manufacture without alteration beyond recognition that they still belong to the same group of minerals. Others alter very materially both in chemical composition and in mineralogical character by combination with the other minerals or with the basic lime and magnesia. Then with regard more particularly to the lime and magnesia, if the mineral impurities present form into mineral compounds at the temperatures of calcination, what effect has that had on the lime present and on the magnesia present.

20.—*Melting points of the individual constituent compounds.*

We know that the oxides, magnesia and lime, when finely divided and intermixed, and when fired at very high temperatures, separate out into the individual oxides, magnesia on the one hand and lime on the other, without in any way forming compounds.[11] But whatever compounds have been formed by the mineral impurities during calcination must undoubtedly react more widely and at lower temperatures with the finest particles of the brick when that is being fired.

It would therefore be interesting to consider in detail, and to know the effect of the presence of, on either or both of these oxides, the impurities, silica, iron and alumina, both separately and together. Most interesting reports of these[14] have been prepared by the Geophysical Laboratory, Washington, which show that while magnesia compounds and lime compounds have melting points ranging between 1,500° C. and 1,550° C., any compounds including both the magnesia and the lime have melting points at at least 150° C. lower. From this point of view it is clearly evident that lime should be eliminated in every way possible, also that if lime is to be present to the extent that is the case now, there is all the greater need for the impurities being distributed equally throughout the magnesia, which can only be done by having the magma that is being formed of such a consistency as will enable it to travel through the magnesia crystals to the furthest point that the most suitable magma can reach.

21—*British Magnesite Bricks.*

No true estimate of the standard of the British made magnesite bricks can be arrived at that does not take into account the furnaces in which they are used, the constancy of the highest temperatures attained, the variations of temper-

ature at which the furnace is worked, the atmospheric conditions of the furnace (reducing or oxidizing), and, most important of all, the quality of steel produced and the quality of slag produced, which are governed by the kind of charges fed into the furnace. Any comparison of standard must be expressed in terms of work accomplished in furnaces that are doing similar work. The reports that are given of the number of heats that are attained in many of the Continental furnaces bear no comparison to the reports that are current about British furnaces dealing with molten iron or basic pig from the Cleveland blast furnaces, for instance, as these Continental furnaces are in many instances using scrap almost entirely, or in others are handling qualities of pig iron, or producing qualities of steel that do not require the extreme furnace conditions that obtain with us.

We have, however, the results that have been attained in the past using Austrian magnesite bricks in this country, and these can be compared with the present results using Greek magnesite bricks in the same furnace. These are in basic open-hearth furnaces, pig iron mixers, Talbot furnaces and electric furnaces. On the whole the result is quite satisfactory enough from the steelmakers' point of view. It is only in exceptional cases, as in electric furnaces, that we magnesite brickmakers have definite enough reports of the comparative life of our bricks to enable us to form opinions; but from what I have myself noticed there are the same difficulties being experienced with all the British made bricks, even in open-hearth furnaces and in pig iron mixers, only the test is not so severe and it takes a much longer time (weeks instead of days, perhaps) to make themselves even evident to the senses of one who has watched the results in electric furnaces.

The difficulties experienced are: (1) Spalling, (2) inability to withstand the corrosive action of the basic slag, causing frothing, with great porosity at the end exposed to the slag, and (3) inability to withstand the great strain that there is in the roofs of electric furnaces, where the spalling becomes excessive and where in the rise of the arch the upper bricks are inclined to lose their shape, thus altering the curve of the arch. Using Spæter magnesite bricks in the past in one electric furnace I know about, the number of heats of steel obtained were 120 compared with 75 heats now obtained with one lining of Greek magnesite bricks. In another electric furnace the Spæter magnesite bricks in the side walls withstood the action of the molten steel and of the basic slag without showing the frothing and porosity that can now be noticed. In a third electric furnace, it was always possible with Spæter bricks in the past,

even when the furnace hands were not as experienced as they now are, to get good results with magnesite bricks in the roof.

Another difficulty experienced with British-made bricks is in the bottoms of basic open hearth furnaces, pig-iron mixers and Talbot furnaces, when after 3 to 5 months' use some of the bricks are crumbled to dust.[15] The bottoms of these furnaces are built with magnesite bricks, and sintered dolomite is covered over them to a depth of 12 to 15 feet, rammed on in layers of about 3 in. thick. At the corners of the ends and sides of the metal baths the embanking of the dolomite leaves that much thicker there, and it is particularly at these places that the difficulty is experienced. The sintered dolomite is previously mixed with dehydrated tar, and each layer of 3 in. is generally sintered in position by gas-firing but the whole dolomite bottom may be rammed on in layers of 3 in. without that. In the former case an addition is made of 10 per cent. of basic slag, and in the latter case the addition to the lowest course is generally 20 per cent. basic slag falling to 10 per cent. for the top course. The greater addition of slag for the bottom course is to ensure that the furnace temperature will be able to penetrate well enough to thoroughly sinter the mass to the bottom and give a good foundation for the metallurgical operations. In the past, in place of dolomite, it was found better to use Austrian pea-size magnesite, and even with that the additions of slag were made in the same proportions, the greater percentage being used for the lowest course in ramming the magnesite bottom. In those days the Austrian bricks could be rebuilt many times in the furnace, even along the side walls in proximity to the embankments, and particularly to the discharging spout. At the latter part they might be thoroughly fused into a solid block, but that was thoroughly satisfactory as it was the strongest foundation for what it had to carry.

Now using British-made Greek bricks when the embankment is being repaired the bricks have to be entirely rebuilt right along the sides and down to the bottom flat to get a good foundation, as those that have to be removed can be dug out with pick and shovel as they have fallen more or less to dust. If whole they have no cohesion of particle, and in fact can be rubbed to dust like bath bricks.

On one occasion I had magnesite bricks refired in luted crucibles, the bricks being surrounded by coke dust, in order to test the effect of the most extremely carbonizing atmosphere that could be had, and the result was that in nearly all cases the bricks had altered from brown colour to white, and parts at any rate of the bricks, and in some cases the whole brick had disintegrated without evident disintegration of the particles

themselves. Some of these luted crucibles were fired in the tunnel kiln referred to in my remarks during the discussion of Mr. Maxwell's paper about gas-fired kilns, in the last volume of the TRANSACTIONS, in which the temperature recorded by the optical pyrometer was about 1,200° C., and others of the crucibles in our own kilns which were firing magnesite bricks at about 1,500° C. An interesting point is that the disintegration only comes about if the firing ceases at the comparatively low temperature of the tunnel kiln. At temperatures of 1,500° C. there was not the same tendency, or at that higher temperature the bricks within the luted crucibles had re-assumed their normal stability and colour. It has been suggested that the disintegration of the bricks to their particles is due to crushing strain under heat, but there is no comparison between bricks that have been submitted to crushing strain and what is evident in the bottoms of the steel furnaces. In many cases the bricks that are taken out whole have little more than the strength of green unfired bricks, and they have no ring when struck together. Yet they have not lost their shape nor altered in size. An interesting communication about magnesite bricks by H. Le Chatelier and B. Bogitch[16] gives data about their resistance to crushing strain at various temperatures. It has to be remembered that in practice it is only the end of a magnesite brick that is subjected to a temperature of 1,600° C. The centres of the walls of any furnace do not approach that temperature. The extra heat only affects ½ in. to 1½ in. of the bricks, and in the lower courses of the furnace walls at the slag level the crushing strain is only about 25 lbs. per sq. inch. At the centre of the baths of the furnace it cannot be much more. It may be said, therefore, that the critical crushing strain for the temperature attained in the lowest course of the bottoms of basic open hearth furnaces is not experienced, and this therefore cannot alone account for the disintegration of the bricks unless the factors alter with long continued lower temperatures. Probably the temperature experienced in the lowest courses does not exceed 1,250° C. unless the metal breaks through the dolomite bottoming on top of the magnesite bricks. It is due to the continual wearing of the dolomite bottoms that variations of temperature are experienced by these bricks, and they must be able when required to withstand the full temperature of the molten metal. In furnace bottoms I have seen there was no evidence of there having been experienced any weakness of the dolomite bottoming, nor of the disintegrated magnesite bricks having experienced variations of temperature due to the proximity of molten metal.

It is also well known that steam has a disastrous effect on all magnesite bricks, even Austrian bricks being similarly affected, and falling to an impalpable powder in the course of a few hours. These impalpable dusts are generally of lighter colour than the magnesite was in brick form; but there is not the uniform white colour experienced in the previous case. As, however, in the experience cited the particles had not fallen to impalpable powder the cause of the disintegration was not due to steam action.

It is possible that in the bottoms of basic open hearth furnaces with the dehydrated tar becoming liquid with increase of temperature and percolating down between the magnesite bricks the carbon of the tar affects the magnesite and causes the bricks to fall to powder state or lose their cohesion of particle; but the main fact is that that was not the case with the Austrian bricks containing sufficiency of impurities (and possibly because they have highly complex iron-alumina impurities) required to thoroughly sinter the brick into a homogeneous mass. This would seem to indicate that at any rate for basic open hearth practice the bricks should approximate to the Austrian bricks.

When considering the crushing strain of magnesite bricks I find that two of the factors requiring consideration as affecting that are (1) the temperatures at which the bricks were fired in manufacture, and (2) the nature of the impurities; but more important than these is (3) the porosity of the finished brick. With bricks of equal firing, and of the same magnesite, the less the true porosity the greater the crushing resistance at any temperatures to which I have had bricks fired.

With regard to the attack of the furnace slag and the oxide dusts of the atmosphere of the furnace, bricks absorb these impurities in the first instance through their pores; the later chemical alterations of the magnesite taking place to the extent that the impurities have been able to penetrate the pore spaces, which is within a certain distance from the surface in each case. That penetration is dependant on the area of the pores, and the viscosity of the penetrating slag or metal at the temperatures experienced. The chemical alteration takes place when there is sufficient penetration of the impurity, but beyond that the impurity can travel and be held in solution by the mineral of which the brick is composed. As soon as the percentage impurity held in solution reaches a certain limit the chemical alteration proceeds, in all cases causing an alteration of the microstructure into one that is recognised as pertaining to minerals of that definite percentage analysis.

But beyond that change in microstructure brought about by the chemical combination there is the physical change called allotropy, which allotropic change is induced by the activities set up by heat or in the interaction of the earlier combining oxides, and its development is due to the earlier energy with which the chemical change was proceeding. If the magnesite is pure it may be expected that the attack of the impurity on the surface of the bricks exposed to the furnace will cause a more violent interaction locally. If the lining was of the same analysis there would not be this violent interaction; but of course at such temperatures as are experienced the lining made of the same material would not have anything like sufficient stability. There is, however, a point of saturation of the pure magnesite with certain impurities beyond which the further saturation is not inclined to be rapid at the highest temperatures when the attack of the further impurity of the same nature is on one end of the brick only. This point of saturation has produced a definite mineral compound, and these closely related mineral compounds have characteristics very similar to those of Austrian magnesite bricks.

In basic open hearth practice the furnace conditions are not so severe as to destroy easily the highest qualities of magnesite bricks. It has been stated by the general manager of one of these plants that he has never experienced bad Austrian bricks. But micro-examination of bricks of different brands after refiring to 1,750° C. shows that one is more stable at such temperatures than another. The Hungarian bricks are perhaps of more variable quality, the raw material requiring more careful treatment and separation of the excess impurities. The following quotation records one experience in America[17] :—

"In 1903, according to Alexander and Leibermann, the total quantity "produced (7,000 tons) was exported. That more was not produced and "exported was due to the entire renovation of the Hungarian works, as a "result of the complaints of the American buyers.

"In Hungary, magnesite cement, made of fully calcined ore, and magnesite "mortar, made of semi-calcined ore, are distinguished. The first is prepared "at a temperature of 1,570° to 1,600° Celsius, entirely cooled and ground to "fine dust. The second is made at a temperature of only 700° to 750° Celsius, "and is likewise ground. The former is used for lining the bottoms and sides "of smelting furnaces, the latter (caustic) for laying the magnesite firebricks "when making such furnace.

"The cement is prepared by the Hungarian Magnesite Industry Co. at "Jolsva, and by Alexander & Liebermann at Ochtina.

"The former company prepares bricks and other products of cement, but "the charge has already been made, says Mr. Liebermann, that some of the "bricks were made of Freund's magnesite from Hacsava (near Nyustya) and "found fragile and not compact. The complaint against the Jolsva bricks has "been that they contained too much iron and silicate. The former Pittsburg

"buyer of Mr. Liebermann's Ochtina bricks purchased some 2,000 tons annually, "as the best in the market. Germany also purchased the Ochtina magnesite "bricks prepared by the Nyusta company previous to its purchase by Freund. "The last-named gentleman has attempted to put on the market technically "better bricks, but his efforts are unavailing to win the American trade, so "much desired, since there is still 10 to 15 per cent. silicates to be found in "the bricks."

At the time that this report was published it was stated in the same report that the Veitsch Magnesite Co. was trying to control all the Austrian and Hungarian markets. It would appear from first examination of the report that the difficulties that the Hungarian works experienced in trying to recapture the American trade after the works were reorganised were greatly increased by the close competition of the Veitsch Company and by the statements about the quality, such as those above relating to the analyses. Most undoubtedly the Veitsch bricks themselves held 10—15 per cent. of ferro-magnesian silicates. The quality of the resulting brick depends on the treatment that these silicates get in the course of manufacture and the uniformity of the resulting product. It could not have been the analysis that was wrong when the bricks were complained about, but the quality of the bricks themselves owing to the treatment they received in the course of manufacture.

These Austrian and Hungarian bricks are generally without the full brand. Some of them have letters and others have marks. But the majority appear to have been sold without distinguishing mark, and in many cases have been sold under the generic term Austrian magnesite bricks or Spæter bricks without the distinctions being recognised. With close examination of the fracture without magnification the different brands are easily recognised; but with micro-examination the distinctions are very marked. As a rule the main distinction is the greater presence or absence of ferro-magnesian silicate; but the trained eye detects many other features, such as size and shape of particle and the percentage of the various gradings, as well as the microstructure of these particles and the varieties of microstructure in bricks of any brand. The best have almost absolute uniformity of microstructure. For the future there need be no doubt about the maker of these bricks. Buyers could purchase on the certified microphotograph of the section of any one average brick. But, fortunately, such an occurrence as the buying of Austrian bricks by British users will not be necessary, as I am confident that the manufacturers in this country of magnesite bricks from Greek magnesite will soon be able to produce a substitute that the Austrian makers cannot beat as to quality, and will not be able under post-war conditions to beat as to price.

I have one report in particular[18] that can give a direct comparison between our Greek bricks and the Spæter magnesite bricks, that I believe will help to bring out how closely our bricks can resemble these Austrian bricks in some respects, and yet differ from them as we see from the facts I have given about these electric furnace tests. The following is a comparison of the average chemical analyses:—

	Eglinton	Spæter
Magnesia	87·57	88·22
Lime	3·25	0·87
Iron and Alumina	2·22	8·52
Silica	6·90	2·35
	99·94	99·96

The specific gravities of the two bricks were 3·41 and 3·61 respectively. The water absorbed by 100 parts by weight of brick was 4·07 parts for the Eglinton brick. This test was not given with the Spæter brick. Crushing tests under heat on ⅝ in. cubes of the two bricks were made, and gave the following results, but we were informed that they must only be regarded as approximately correct:—

	Eglinton	Spæter
Metric tons to crush	5·10	5·30

The average analysis of the Spæter brick was not given, and what I give above is that taken from the analyses advertised by the Veitsch firm. I have, however, micro-sections of each of the actual bricks that were submitted to the crushing test. Pl. X and XI, Figs. 1 and 5, give photographs of Spæter bricks.

There is no brick being made that cannot be recognised as being made by a particular maker; but, generally speaking, one can say that in Britain at present we have two types of brick. The one type is made from finer ground material and has a less weight per thousand; the other is made from less finely ground material, and has greater weight, but if anything a more variable weight, per thousand. The lighter brick weighs about 72—76 cwts., and sometimes to 80 cwts. per thousand; and the heavier brick averages from 82—86, and sometimes to 88 cwts. per thousand.

In the former there is finer particle, and on the whole a more complex colour scheme; and in the latter, both with and without polarised light, there is greater light and shade between particle and magma, and between some particles and others.

It is the duty of a petrologist to tell us what the compounds

are that have been formed. What I wish to do is to direct attention, both under polarised light and otherwise, to (1) the magnified particle and its microstructure, (2) the particle that has been penetrated by the magma, (3) the magma itself, and the varieties of magma, (4) the distribution of particle and magma in (*a*) the bricks of light weight made from finely milled material and (*b*) those of greater weight made from less finely milled material. In particular I wish to direct attention to the light coloured particles and compare them with sections of calcined magnesite fired at various temperatures. These sections of calcined magnesite will be referred to in detail later. The immediate object is to bring out what a considerable percentage of particle remains in the state of calcined magnesite, even although that magnesite has been calcined at the highest temperatures attainable in the calcining kilns that we have in this country, and to show that the impurities surround our particles rather than interpenetrate them, as has been shown is the case with the magma and the particles of Austrian magnesite bricks.

The area of any field viewed by the microscope is only $\frac{1}{2}$ inch or $\frac{1}{8}$ inch in diameter. The last gives very high magnification and is only good for detail. Many manufacturers would even object to looking at any $\frac{1}{4}$ in. or $\frac{1}{2}$ in. section of their products, holding that no field of vision could be regarded as showing the average of their product, when each field varies under ordinary light and often under polarised light so considerably. With some experience of microscopic examination that opinion vanishes. The memory retains so much after careful and sustained examination of one's own product (no doubt in comparison with those of our direct competitors) that you can often recognise micro-sections of particular bricks being very like micro-sections you have seen of some particular brick earlier, and you can at once lay your hands on that one. I also find microscopic examination of the moving picture as in a cinematograph show to convey a definite picture to my mind of the products of the respective makers. I can retain in my memory the general appearance of the particles, magmas, and colour schemes of the average bricks of each of the makers, in this country, that I have examined. This moving field is, I think, particularly useful in considering the whereabouts of the magma, and its characters under polarised light.

IMPROVEMENTS TO BE BROUGHT ABOUT.

22.—*Deadburned Material.*

I now wish to direct attention in detail to sections of raw magnesite and then of calcined magnesite, some of these being calcined to a temperature of about 1,250° C., and others being fired to a temperature of 1,750° C. In particular I would like to point out: (1) The minute granular forms of the Indian and Greek magnesites calcined at 1,250° C.; (2) the alteration that is taking place in the Indian magnesite when calcined at a temperature of 1,750° C. in an electric furnace, and in particular how that alteration seems to be greatest at the places where there was evidently a certain degree of impurity present, not necessarily at the outer edge of the magnesite, but in some cases towards the inner core; (3) in the case of electrically calcined pieces of Greek magnesite fired to very high temperatures (about 1,850° C.) how the particles have completely altered towards the impurity, and how far that alteration has been able to spread. Evidently there are three recognisable alterations if one can judge from the sizes of microstructure produced. Beyond the well recognised alteration there is a distinctly neutral white band into which the alteration is evidently penetrating very slowly, and beyond which there is distinctly recognised the unaltered mineral; (4) a more interesting section still is seen in the case of Greek magnesite calcined in a modern shaft kiln for a very much longer period, but at a lower temperature, in which section the change of mineral particle is seen to have spread more or less throughout the mass, showing that it is not so much high temperature as long continued temperature under highly reducing atmospheric conditions that will be most likely to bring about economically the change desired; (5) these two last sections were taken through a piece of calcined stone that showed on the outer crust of one of its faces the corrosive effect of the impurity, with the object of ascertaining how far the impurity has interpenetrated and attacked the mass, and it was only after examination that the wonderful alteration in the crystal particles was observed. Sections were also taken with planes at right angles to that plane showing transverse sections of the material closely in contact with the impurity, and also of the material furthest away from it, and thirdly of the material equidistant from these two points. These transverse sections show more clearly still the alteration that was made in the crystals and indicate, I think, how much further we can depend on bringing about that alteration with our attention directed to that end.

There is a close parallel between these microstructures that are now appearing in these magnesites and those that one sees in the sections of Austrian pea-size and Austrian magnesite bricks, particularly in the sections of that brick taken from Messrs. Beardmore's furnace. There is the massive crystalline appearance now in the Greek magnesite, even in places where there is no coloration, showing that the allotropic change has not been brought about wholly by the presence of impurity, and these crystals remind one most forcibly of the light section of Beardmore's Austrian brick. There is undoubtedly still some difference, probably due to the mineral in Beardmore's brick holding in solution more or less of the iron compounds; but I feel confident that with careful treatment with that end in view we could convert amorphous Greek magnesite in the economical course of manufacture so that it would have the microstructure that these Austrian bricks naturally have.

23.—*Deadburning Plant.*

I am quite certain that the Veitsch Company calcine in rotary kilns, although originally they used shaft kilns; but with mineral holding so perfectly in proportion its own needs of impurity one can well understand the temperatures attainable in rotary kilns doing the deadburning. If we, using Greek magnesite (with reduced silica and lime content possibly), ground our magnesite into fine powder in the carbonate state and thoroughly incorporated throughout the fine dry material the necessary percentage of ferrous carbonate, it is a question whether we could use rotary kilns also.

It may be asked if all the factors mentioned earlier could be taken into account in deadburning by rotary kilns; if the magma in the finished bricks could be provided for by suitable addition to the raw magnesite in the ground state; if the finest particles with this addition of ferrous oxide would be refractory; if they would sinter sufficiently to be deadburned; and if the atmosphere of the rotary kiln could be retained sufficiently reducing to ensure that the iron could remain throughout in the ferrous state until it had thoroughly penetrated the magnesia particles. We can see that these particles, one-sixteenth of an inch in diameter, are divided into wonderful rosettes of minor particles. We have also known in the past that in Austrian magnesite these particles grow in the course of firing in rotary kilns, so that mineral particles three-eights of an inch cube are formed whose section is wonderfully uniform, sometimes opaque when greater impurity is present, and sometimes almost

of the pattern of the mineral periclase when that holds 5—8 per cent. impurities, as is now disclosed by the microscope.

With the ferrous carbonate held in the mineral particles of the raw magnesite, rotary kilns have a much better chance of bringing about the thorough reduction of the magnesia and iron, and they would have very much greater difficulty in bringing about that thorough reduction if the two carbonates (magnesite and ferrous carbonate) were not present in crystal formation, and even if they were in the most intimate state of division and mixing that we could bring about in dry sifting and dry mixing plants and rotary kilns. We must retain a highly reducing atmosphere in the rotary kilns, and I believe great difficulty would be experienced in securing a rotary kiln lining able to stand the temperature that would be required in that reducing atmosphere.

24.—*Periclase.*

Just as silica brickmakers should study the physical properties of minerals high in silica like Sheffield ganister and Dinas rock that hold varying small percentages of impurities in the crystal, which in most cases approximate in quantity to the impurities held by the basic mineral periclase, so I believe that that mineral in its various manifestations as found distributed throughout the world in rock aggregates or mineral deposits that hold it, is what those interested in magnesite have to study so as to get to know the percentage impurities of the several kinds that we may expect to find to be able to be held in solution by the artificial periclase, at varying temperatures, under furnace conditions experienced in metallurgy.

In Dana's reference to periclase, and particularly in the notes about artificially prepared periclase, it is remarked how the mineral will separate out from the lime compounds formed. For notes about the microstructure of periclase see description of Pl. XXV, Figs. 1 and 2, in index of plates.

25—*Moulding the Bricks.*

It is notable that Wedding reports that a pressure of 300 tons is applied in the moulding of the Veitsch magnesite bricks. With such a pressure and with our existing grinding plant we could make our standard size bricks $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ in. to weigh about $5\frac{1}{2}$ tons per thousand against Spæter's 87·5 cwts. per thousand. Already with the pressure we employ we can by making suitable adjustments of the milling and moulding plant raise the weight of the bricks from the standard weight

of 4 tons per thousand to fully $4\frac{3}{4}$ tons per thousand. The question of pressures to be employed is intimately bound up with that of the milling of the dry material, and that again with the deadburning of the magnesite. The higher the deadburning temperature the finer we can grind our material, and the greater the pressure we shall have to employ to mould that finely ground material to make the weight of our brick that of the Spæter standard. This is a matter intimately bound up with the manufacturing works' practice of each maker.

26.—*Conclusions.*

I would like to accentuate the main conclusions that I think should be drawn from microscopic examinations:—

(1) That microstructure growth can take place with proper application of heat.

(2) That the growth takes place more quickly and more uniformly if there is a uniform percentage of impurity throughout the magnesite.

(3) That the impurity-magma must be able to interpenetrate the finest interstices of the magnesite particles, holding these together by the magma (figuratively speaking) oozing through them, rather than by the magma coating them.

(4) That if the impurity cannot interpenetrate the particle, or can only penetrate the particle partially, the percentage impurities should be correspondingly less, as they will occupy the interspacings between the larger particles.

(5) That if these particles are unaltered from the amorphous state in which they are when calcined at 1,250—1,500° C. without the presence of penetrating impurity, and without the highly reducing atmosphere of modern gas-fired shaft kilns, and the bricks made from that magnesite built into furnaces working at white heat, we have these particles continually being altered from the small to the large crystal state with greater porosity between the particles, until, by continued spalling of the face of the brick next the furnace where the greatest contraction has taken place the new section of the brick with altering particles is faced with the direct action of the slag which can penetrate the pores, causing frothing with increased porosity.

(6) That in specimens drawn from consignments, recently received from the Greek mines, of 200 tons of dead-burned Greek magnesite which had been calcined at about 1,750° C. in modern gas-fired shaft kilns the microstructural growth has taken place almost throughout the specimens drawn, but without perfect regularity of growth.

(7) That if the attention of the works' management was directed to this fact the conversion of the crystal growth from the amorphous crystalline state would most probably be more uniformly attained.

(8) That when in these specimens of shaft calcined magnesite there is the presence of ferric oxide, within a certain distance from that impurity the conversion of the crystal growth from the amorphous to the massive crystalline is much more uniformly attained and is closely comparable to the Austrian product.

(9) That the British-made Greek magnesite bricks most closely corresponding in microstructure to the Austrian magnesite bricks are those which have been found to show least alteration after use in furnace linings.

(10) That the microscope examination of deadburned Austrian magnesite and of Austrian magnesite bricks shows crystal growth, the micro-section of the deadburned product showing sometimes greater density and sometimes less regularity in micro-structure than that of the finished magnesite brick; which shows the great regularity of structure brought about by hydraulic pressure in the moulding of dense material finely milled and intimately mixed, each particle of which has nearly similar microstructure when the bricks are fired.

The opinions expressed in this paper were formed quite apart from any scientific enquiry and on practical lines that any manufacturer might have gone on; looking at the materials that I was dealing with either by examination with the eye or by examination with the aid of reflected or transmitted light with high magnification, with the one object of learning as much as I could about the magnesite particles. In the course of the optical examinations of the micro-sections that were prepared I could see the very great alteration that took place in magnesite after continued heat treatment, and the great

regularity of structure of the best bricks. As the new slides came to me from the makers of the slides each consignment confirmed the earliest views that had been formed, and my paper is simply a presentation of these early views. It is for petrologists to say what compounds have been formed that account for the various colorations; but manufacturers can see for themselves that the colorations exist in varying proportion, depending on the heat treatment that the magnesite receives, and that both with polarised and non-polarised light the coloration of the impurity changes very much with every change that is made in the regular process of manufacture. Apart from pure science, therefore, there is not the least doubt that the microscope can teach us to appreciate the details of manufacture in a wonderful way that nothing else that I have found has been able to do, in a way, too, that is beyond all doubt when sufficient care is taken in arriving at the primary conclusions.

The most regular microstructure throughout the brick is evidence of the highest excellence of manufacture. Not only can the brick be perfect, but the particles of the brick can be in themselves perfect in microstructure. That never is the case unless the brick is well made and unless the material from which the brick is made is well prepared. Excellence of manufacture is the goal that examination by the microscope guides the manufacturer towards, and the user can by micro-examination recognise that excellence when reached.

I am indebted to Mr. J. R. Lomax, of the Lomax Palæo-Botanical Co., for the preparation of the micro-sections and micro-photographs; to Mr. A. Duncan, of Messrs. A. C. Parsons, Ltd., for the first four micro-sections of magnesite bricks; to Dr. J. W. Mellor, of Stoke-on-Trent, for firing the specimens of the magnesite bricks reproduced in Pl. XXIII and XXIV, and the specimens of Austrian magnesite from the British Museum Authorities reproduced in Pl. III, Figs. 4, 5 and 6, and to his assistant, Mr. C. Edwards, for ascertaining the temperature of incipient fusion of the cones made with the impurities of the magnesite bricks given in Table IV; to Dr. Herbert Smith, of the British Museum, for the loan of micro-sections reproduced in Pl. I, Figs. 1 and 2; Pl. III, Figs. 4, 5 and 6, and Pl. XXV, Figs. 1 and 2; and to Mr. T. Crook, of the Imperial Institute, London, for the specimen of ferro-magnesian mineral reproduced in Pl. XXV, Figs. 3 and 4.

INDEX OF PLATES.

It is advised that these reproductions should be examined by aid of lens about 2 in. in diameter and giving five magnifications.

I.—Raw magnesites; showing (1) and (2) Austrian magnesite, both very pure, one with large crystal structure and the other without structure; also (3) Manchurian magnesite of large crystal structure; and (4), (5) and (6) Greek magnesite of great purity, (4) with microstructure, and (5) and (6) without microstructure. ×8.

II.—Raw Greek magnesite, showing presence of impurity in (1), (2), (5) and (6). The light-coloured areas show the interpenetration of silicate of magnesia; the dark-coloured areas show the opaque pure magnesite.

Fig. 2	Magnesite	contained	52·75	per cent.	volatiles
,, 3	,,	,,	36·80	,,	,,
,, 4	,,	,,	44·00	,,	,,
,, 6	,,	,,		,,	,,

These should be compared with the impurities found in the calcined magnesite given in Pl. VI. ×8.

III.—Calcined Austrian magnesites; showing (1), (2) and (3) deadburned pea-size magnesite from Veitsch Company, also (4) raw Austrian magnesite (Pl. I, Fig. 1) calcined in electric furnace and (5) and (6) raw Austrian magnesite calcined in electric furnace (Pl. I, Fig. 2). These show the diversity of Austrian magnesites, the first three holding considerable impurity. ×8.

IV.—Electrically calcined Indian and Greek magnesites, showing (1) and (2) Indian magnesite, and (3), (4), (5) and (6) Greek magnesite. Figs. (3) and (4) disclose the allotropic change that has been brought about in the short period of firing within a certain radius from the impurity which in both cases was towards the inner sides. The staining from the impurity has not travelled into the fields shown, which only disclose the change that has been brought about by the catalytic action of the impurity at some distance. Bordering on that change there is the neutral band, and beyond that the unaltered opaque magnesite. ×8.

V.—Greek magnesite calcined in shaft kiln, showing (1), (2) and (3) reproduced from one micro-section, and (4), (5) and (6) reproduced from micro-section of a second piece of magnesite that had been more affected by the temperature. ×8.

VI.—Impurities in Greek magnesite calcined in shaft kilns for comparison with those of raw Greek magnesite. Fig. (1) shows porosity in proximity to impurity, which shows pleochroism under polarised light. The light areas show the porosity and the darker areas the ferro-magnesian mineral. Some of the impurities shown in Figs. (2) to (6) are able to be traced in the course of manufacture right through to the finished brick. ×8.

VII.—Map showing deposits at Veitsch and Eichberg of Veitsch Magnesite Co. in Austria.

VIII.—Photographs of Veitsch Magnesite Company's works at (1) Veitsch, (2) Eichberg, and (3) Breitenau.

IX.—Reproduction of Veitsch Company's exhibit at 1893 Chicago Exhibition, showing photographs of raw magnesite. Also showing the check with which they advise that arch bricks should be moulded.

X.—Austrian magnesite bricks: (1) by Spæter, and (4), (5) and (6) by other and different makers. Figs. (2) and (3) show the brick fired in the furnace of Messrs. Beardmore for 2½ years and the development of the white-coloured formation. Fig. (2) should have the colour of the white formation shown in Fig. (3), but that was difficult to reproduce in the micro-section over the whole area. ×8.

XI.—Selected fields from figures in Pl. X, the figures in each plate corresponding. The particular areas can be discovered by examination of the figures in Pl. X with a lens giving 4 or 5 magnifications. The white areas in nearly all cases disclose the white magnesia formation and do not indicate porosity. The difference in colour where there is porosity is marked. The clear area on the bottom margin in Fig. (1) shows that in comparison to the whiter areas in the same figure. ×40.

XII.—Map of Greece showing island of Eubœa and town of Chalcis.

XIII.—Photograph of hill country in Eubœa.

XIV.—Hill of magnesite being quarried.

XV.—Face of magnesite quarry showing entrance to shaft.

XVI.—Entrance to shaft near at hand showing the magnesite in a massive face.

XVII.—Openwork quarry showing earth burden and contorted appearance of magnesite there.

XVIII.—Another quarry showing the magnesite leaving the quarry by rail.

XIX.—View of port of St. John's with calcining plant.

XX.—Map of the deposits.

XXI.—British magnesite bricks. Micro-photographs of prepared faces of the bricks. The white areas show the pieces of calcined magnesite which have been least affected by heat or by inter-penetration of impurity. Such particles have no apparent microstructure. ×8.

XXII.—Micro-sections of special fields of the bricks appearing in Pl. XXI, the figures in the two plates corresponding. ×40.

XXIII.—Micro-sections of parts of the bricks appearing in Pl. XXI after refiring in electric furnace at 1,750° C. These show the great change that comes about in the microstructure of the particle when British-made bricks are refired at the higher temperature, and also the porosity that results. The white areas marked X show this porosity. ×40.

XXIV.—(1) and (3) Austrian bricks, and (2) and (4) the same bricks refired in electric furnace at 1,750° C., also (5) and (6) two Greek magnesite bricks taken from furnace after 12 years' work, referred to by Mr. Brookes in the discussion. The white areas in Fig. (2) show porosity, but in Fig. (4) show the development of the white magnesia formation, there being no porosity in this particular field of Fig. (4). ×40.

XXV.—Periclase and magnesioferrite. (1) Periclase from Monte Somma, and (2) artificial periclase. Cubic structure signifies great purity with perfect opacity under polarised light. Fig. (1) shows segregation of impurity with pleochroism under polarised light where the microstructure corresponds with the microstructures observed most in magnesite bricks. Figs. (3) and (4) ferro-magnesian mineral showing intrusion of iron through magnesia body. ×33.

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DISCUSSION.

Dr. J. W. MELLOR:—There are many questions raised in the singularly interesting paper of Mr. Wm. Donald which merit a rather full discussion. At present, in order to prevent confusion in the use of terms, I need only say that what is here referred to as amorphous magnesite is what I have previously (*Trans. Cer. Soc.*, **16**, 85, 1916) called the low specific gravity form or α-magnesia, and the periclase variety is what I called the high specific gravity form or β-magnesia. What Mr. Donald calls crypto-crystalline magnesite is a mixture of varying proportions of the α and β-forms. I was particularly interested in Mr. Donald's statement that he can recognise the

bricks of particular makers from a microscopic examination of their slices. In that respect Mr. Donald must be far in advance of anyone I know, and I must congratulate him, because I very much doubt if anyone else on this planet could claim to be so expert.

Mr. W. J. BROOKE:—At my last attendance at a meeting of The Ceramic Society here, when a paper was read on a similar subject, I was a pessimist, basing my claim to be a critic through everyday use. The British-made magnesite bricks at that time were a long way behind, and it then seemed that radical changes would have to be made in order to satisfy steel works managers. To-day I am glad to say that British makers are rising to the occasion, and their products have improved wonderfully, thanks to researches like those of Mr. Donald, and the assistance given by Dr. Mellor and others.

At the Stourbridge meeting of the Refractory Materials Section I mentioned that we were installing a new Talbot furnace at the Shelton Steel Works, and I can now speak of practical results. A thicker lining of British bricks was considered advisable than if Austrian bricks had been used, and, as the Ministry of Munitions would not allocate sufficient bricks from any one single firm, we had to make the best of supplies from different makers. In an ordinary basic open-hearth furnace magnesite bricks are chiefly used as a sort of armour-plating; the temperature effect is not so marked as in electric furnace work, but the basic slag works havoc by causing disintegration of the lining. In January last the Talbot furnace was closed down for some minor structural alterations and it was found that in some of the bricks near the slag line softening had taken place and great porosity developed. Basic slag near them was apparently absorbed by the porous bricks and nearly 3 ft. of brickwork was eaten through. In a furnace of this type the magnesite lining is carried well above the tamped dolomite portion, and the behaviour of the magnesite bricks can be readily watched. Some new bricks resembling the Austrian bricks were put in the new lining and have stood as well as the Austrian bricks did formerly. The contraction mentioned by Mr. Donald was in the former case very marked. After 10 days' heating some of the joints between silica bricks and magnesite bricks were $1\frac{1}{2}$ in. wide.

Magnesite bricks in the bottom of the bath of the furnace can last 5 or 6 years as well as they can last $2\frac{1}{2}$ years. I have known Styrian bricks to last 8 years.

I have brought several bricks with me to-night. One was made of pure magnesite, was of good shape, well burned, and

had a crystalline structure almost like the Styrian bricks. Some of these bricks were put in as far back as 1905, and were taken out in June, 1917, having thus been in 12 years. A British brick recently put in the Talbot furnace also shows the characteristic crystalline appearance of Austrian bricks.

As regards weight, each consignment shows great variations. From one truck load I had 250 bricks carefully weighed, and they were found to vary from $7\frac{3}{4}$ to $9\frac{3}{4}$ lb., one or two reaching 10 lb., in fact there was not 2 per cent. of them anywhere near alike. Such extreme variability must greatly affect their behaviour in the furnace.

Thanks to the enterprise of manufacturers like Mr. Donald and the good work of Dr. Mellor and The Ceramic Society, these refractories are much better than they were twelve months ago.

Mr. W. DONALD:—Dr. Mellor has demonstrated clearly in the communication he refers to how we may ascertain the percentage by weight of the magnesite bricks that is occupied by the magnesia particles of low specific gravity (α-magnesia) and that occupied by the particles of high specific gravity (β-magnesia). The α-magnesia particles are those that are unconverted from the amorphous state. The β-magnesia particles of high specific gravity are those which have been most acted on by their proximity to impurity, or by the furnace temperatures and atmosphere.

We see that there are several high-temperature formations and it would be of considerable interest to know the specific gravities that can be associated with each of them. If the conversion of the α-magnesia takes place when the metal or the basic slag can attack it, chemical combination at once takes place, and there is more or less increase of porosity depending on the affinity and the avidity of the base towards the impurity oxides. The porosity appears to be greater the greater the avidity. If the conversion takes place away from the action of the slag impurities, with the heat applied all round the brick as in the brick kiln, there is no spalling, as the contraction takes place uniformly all round. But if the heat is applied on only one end of the brick conversion takes place with contraction of the magnesite particles within $1\frac{1}{2}$ in. from that end.

At the same time there is contraction of the pore spaces due to the tensile strength of the magma. Following on that, when the limit of tensile strength is reached there is rupture, with spalling, when a new face is again exposed to the heat.

With regard to the recognition of each manufacturers' products when examined under the microscope with high magni-

fication, I have no hesitation in saying that I can recognise magnesite bricks made by each of the British makers, and that these bricks are quite distinct from those of American and Austrian makers, whose bricks are also able to be easily recognised from each other.

It is encouraging to hear what Mr. Brooke says about British made bricks used in basic furnaces. I have never experienced bricks that shrunk so much as to have $1\frac{1}{2}$ inches between the joints or that have such variation in weight. But undoubtedly these are two of the primary factors requiring the attention of the manufacturer of refractories. Mr. Brooke is one of the users in this country who has believed in the approximating of the Greek magnesite bricks to those of Austrian make by the addition of impurities, and it cannot be too closely enquired into in what respects there should be these resemblances. In two cases that I have recently known about, bricks that have had additions made to them have not approximated in analysis to that of the Austrian bricks, the additions made having mainly increased the siliceous impurities naturally held by the Greek magnesite, and, judging by my own experiences, such additions do not give such good results as those that make the analysis most closely approach to that of the highest standard of the Austrian bricks. That highest standard I firmly believe to have come about by natural selection over 30 years' experience of the use of bricks in all the steel producing centres of the world, as there is little doubt that the Austrian bricks of variable analysis do not give such good results in use.

The following are analyses recently made of two bricks made by English makers, to which siliceous additions have been made, and also of two Austrian bricks, the last of which I take to be the highest standard known:—

	(a) British	(b) British	(c) Austrian	(d) Austrian
MgO	77·64	82·40	80·80	85·87
CaO	4·75	7·30	2·13	3·25
Fe_2O_3	1·83	1·96	5·88	8·63
Al_2O_3	2·32	1·29	4·14	1·52
SiO_2	—	—	8·03	1·46
Siliceous matter	13·15	6·80	—	—
	99·69	99·75	100·98	100·73
Silica in siliceous matter ...	9·15	4·80	—	—
Specific gravity	3·37	3·48	3·62	3·65
Porosity	28·94	26·45	19·80	16·30

That highest standard I believe to be attainable by British makers from Greek magnesite. Already my company has done considerable work towards that end in execution of orders

for special purposes and for special trial in basic furnaces, the users in each case entering into their specification the alteration of the Greek magnesite that they wish to have made, and each of the users working on their own ideas and experiences.

With magnesite of such uniform quality as Greek magnesite much is able to be done in this way to meet special requirements, and I believe there is a great future for these special quality magnesite bricks. The possibilities are most clearly demonstrated by careful examination of the micro-sections of the manufactured and used bricks.

With regard to the brick from Messrs. Beardmore's furnace, I find on referring to them that the furnace in which it was used was a forge furnace, and that the end of the brick was exposed to a flame of 1,200° C. for the period stated, viz.: 2½ years. Magnesite bricks no doubt last several years longer when built into the foundations of furnaces with a considerable bed of dolomite on top. Eight to twelve years are figures that have been given to me by several users. But this particular brick had been exposed to the direct flame of the furnace while in use. Recently I have collected other bricks showing the development of this white formation, and in particular four Spæter bricks taken from parts of a Talbot furnace in which each was thought to have had to stand a different temperature, and the brick that had the least severe conditions to withstand has practically none of this white magnesia formation after use since 1914. In the brick most exposed that formation has developed irregularly throughout the whole brick.

(Added July, 1918.)

I have delayed revising the preliminary conclusions come to until I had considered in detail the latest micro-sections, and until I had the opportunity to discuss the matter with several of the users, so that I could formulate the questions that seemed to me to require most consideration between the manufacturers and the users.

I would like to state the conclusions with regard to the possibility and desirability of the magnesite bricks being made from Greek or Indian magnesite, having added to them such additions as may well be agreed on between the manufacturers and the user, and in such a way as will perhaps best bring out what I believe the future development must be, even though that development must wait for the users' acceptance of these conclusions.

(A) Austrian Bricks.

1.—Magnesite bricks made from Austrian magnesite have been universally used for thirty years.

2.—Such bricks can be re-used several times with better results, if anything, each time they are used.

3.—They are made from magnesite of varying analysis, the best of which approximates to within 2 or 3 per cent. of the analysis of the bricks manufactured by the Veitsch Magnesite Company, this being done by careful elimination by washing and magnetic-separation plants when necessary, or by mixing the purer beds with those less pure.

4.—The micro-sections of each of the Austrian bricks is quite distinct, and is easily recognised, and the best bricks have the most uniform microstructure throughout each particle.

5.—The specific gravity of Austrian bricks is higher than that of British-made Greek magnesite bricks, the average of the former being 3·572, and that of the latter being 3·435.

6.—The Austrian bricks weigh on the average 10 per cent. to 15 per cent. more than the standard English bricks.

(B) Greek Magnesite Bricks.

7.—Greek magnesite can by the addition of suitable catalysts assume at convenient temperatures (about 1,400—1,500° C.) the microstructure of the Austrian magnesite. At considerably higher temperatures the allotropic change can be brought about without catalytic agents being present.

8.—The allotropic change disclosed by examination of the microstructure varies in dimensions and character at uniform heats with the nature of the catalytic agents present.

9.—It also appears to be affected by the density of the bricks when moulded, the most dense brick attaining the most perfect microstructure more easily than the more porous brick.

10.—These additions can be conveniently made in the economical process of manufacture, and not only tend to economy of manufacture, but may themselves be found less costly ton for ton than calcined magnesite.

(C) Furnace Linings.

11.—What are wanted are bricks that present a very dense face to the corrosive action of the furnace slag, and to the less strenuous action of the oxide dusts in the furnace atmosphere.

12.—Both of these have easily recognisable effects on the various qualities of magnesite bricks that have been available in the past. Micro-sections of the slagged ends of magnesite bricks, or of the ends that have been exposed to the furnace atmosphere disclose that.

13.—The action is disclosed in part by the porosity of the bricks exposed to the slag. Micro-photographs of the porous slagged ends of Austrian bricks can be compared with micro-photographs of the slagged ends of Greek bricks, and with the same magnification the difference in micro-photograph is noticeable, there being evidence of less porosity in the case of the Austrian bricks given the same furnace conditions.

14.—There is distinct evidence in the examination of slagged ends of Greek magnesite bricks that the greater porosity is due to frothing induced by the chemical interaction of the pure magnesite particles and the slag. The less porosity in the case of the slagged ends of Austrian bricks indicates that there is not the same activity in the chemical interaction that takes place.

15.—Bricks made from Greek magnesite with the presence of such impurities as bring about the allotropic change in the magnesite particles appear to have a better resistance to the slag and furnace atmosphere.

16.—This appears to be due to the formation of what may be called mineral alloys, which have great stability within a wide range of high temperatures, and which, having great density themselves, do not contract in particle to the same extent as is the case with pure Greek magnesite particles.

17.—If micro-photographs of British-made Greek magnesite bricks are compared with micro-photographs of these when refired at 1,750° C., there is evidence in the latter of much greater porosity between the particles. The crushing strain of porous cubes is much less than that of cubes moulded under great pressure.

18.—There is also distinct evidence in the examination under high magnification of prepared sections of Austrian magnesite bricks refired at 1,750° C. that the particles in which the allotropic change has best been brought about are detached from the surrounding material owing to the particles having contracted and become much more opaque.

19.—Contact with furnace slag appears to have less effect on Austrian bricks than on Greek bricks, unless the latter have been made by methods involving heat in firing and pressure in moulding, not attainable in present-day magnesite brick manufacture in this country.

20.—Greek magnesite bricks made under ideal conditions as to heat and pressure, in which the allotropic change has taken place throughout their particles, show a resistance not only to all the temperatures of furnace practice up to 1,750° C., but evidently also to slag and furnace atmosphere better even than Austrian bricks. It is such a brick that Mr. Brooke refers to in the discussion. After 12 years' firing in the furnace protected by the dolomite covering of the bath these bricks made from Greek magnesite and moulded under hydraulic pressure have a micro-section equal to that of the best Austrian bricks, and a density unalterable by further firing in electric furnaces up to 1,750° C.

21.—Such bricks have a density so great that their weight is 90 cwts. per thousand for size $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ in. against the weight of 76—84 cwts. per thousand for present day British bricks, or $87\frac{1}{2}$ cwts. per thousand for Austrian bricks, both of the same cubic contents.

22.—The alternative to adding ferrous impurities to Greek magnesite is to have the silica-lime impurities present in such percentages as will enable the allotropic change to be brought about in modern gas-fired kilns.

23.—The magnesite presently (in July, 1918) being imported into this country appears to have this sufficiency of impurities. Two average analyses of this are as follows:—

MgO	84·80	85·26
CaO	3·81	4·21
Al_2O_3	2·94	3·09
Fe_2O_3	3·68	3·61
SiO_2	4·77	3·83
	100·00	100·00

24.—This magnesite calcined at a high temperature ground to a fineness approximating to that of Austrian bricks and moulded in brick form under a pressure of 150 tons per brick gives a brick of size $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ in. weighing 84 to 85 cwts. per thousand, which brick has a porosity measured by Mellor's porosimeter of 16 per cent. This porosity of 16 per cent. is that of the best Austrian bricks.

25.—Such a porosity is more than sufficient to allow of the early expansion on heating without disrupting of the brick.

Expansion of Magnesite Bricks on Heating (Le Chatelier).

	200° C.	400° C.	600° C.	800° C.
	mm.	mm.	mm.	mm.
Austrian magnesite brick ...	0·21	0·55	0·85	1·10
Grecian magnesite brick ...	0·25	0·52	0·79	1·02

26.—$2\frac{1}{2}$ in. cubes cut from such brick have a crushing strength of 30—34 tons ultimate pressure. $2\frac{1}{2}$ in. cubes cut from bricks with 30 per cent. porosity have a crushing strength of about 16 tons ultimate pressure.

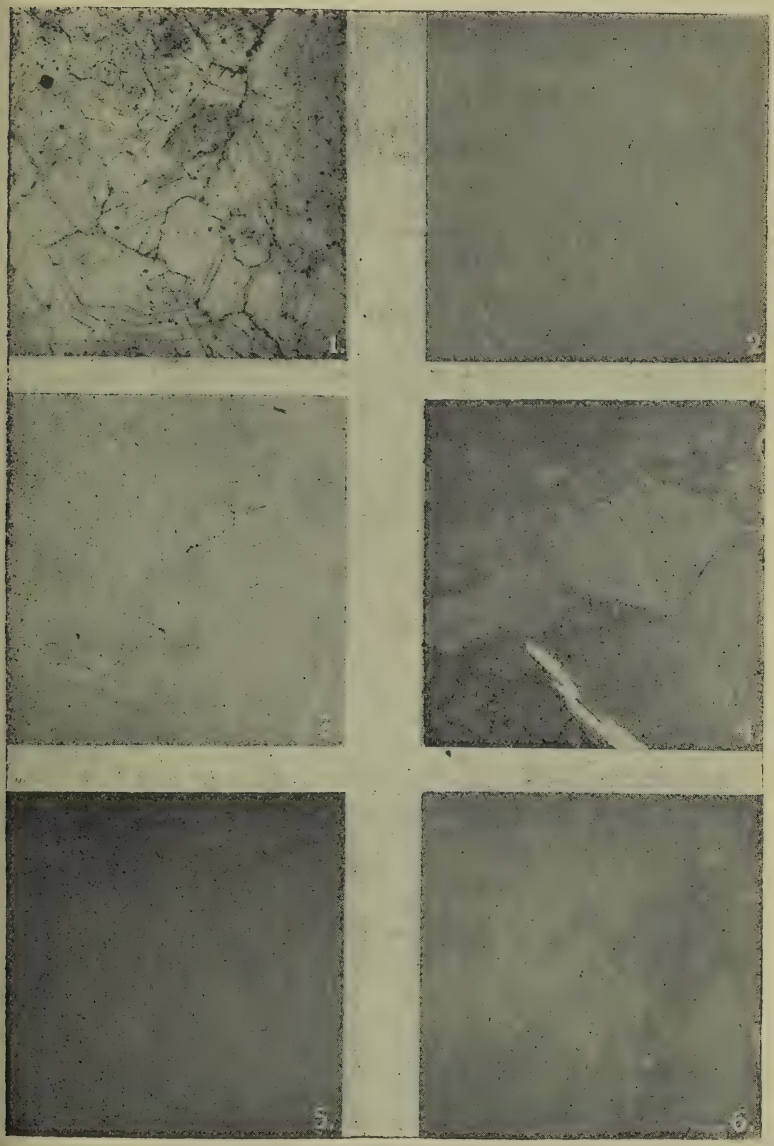
27.—At temperatures of about 1,450° C. the crushing strain of about 15 lbs. per square inch will reduce the cubic contents of porous magnesite bricks, and they will have the same porosity, density and conductivity that less porous bricks originally have. This tendency towards squatting which varies with

variation of porosity is hardly noticeable in densely moulded bricks, but in any case can be measured. To whatever extent squatting takes place the jointing of the brickwork is weakened.

With no crushing strain the specimens fired at 1,750° C. increase in porosity through the contraction of the particle. It is only the end of the brick towards the combustion zone that experiences that contraction of the particle to the fullest extent.

With that crushing strain of 15 lbs. per square inch, the squatting that has been experienced earlier in the firing at about 1,450° C. may have reduced the porosity of the bricks from about 25 per cent. to about 22 per cent., and at that end of the brick next the combustion zone this porosity of 22 per cent. may be increased to 25 per cent. through the later contraction of the particle at the highest temperature. This would leave the end of the brick next the combustion zone with 25 per cent. porosity more easily affected by the crushing strain than those parts of the brick that had only a porosity of 22 per cent. This is proof that the original density of magnesite bricks as manufactured is a factor of prime importance.

28.—The question is one of economical manufacture to attain the best ends possible, and that seems best accomplished by bringing about in bricks made from Greek magnesite the microstructures evident in the Austrian bricks by the presence of such catalysts as will enable the allotropic change to be brought about at the temperatures (1,400—1,500° C.) attainable in modern gas-fired kilns.



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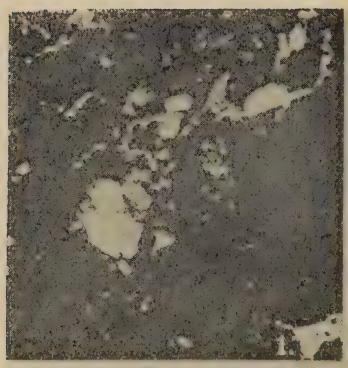

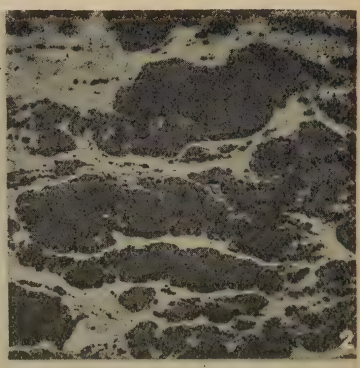

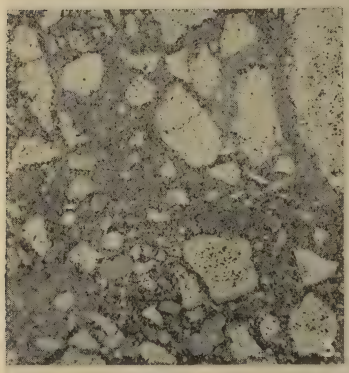

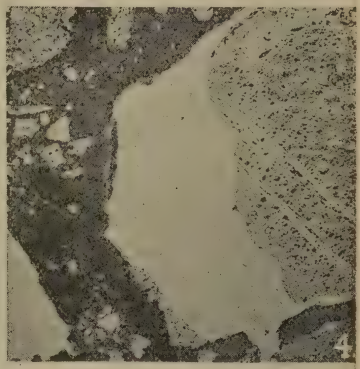

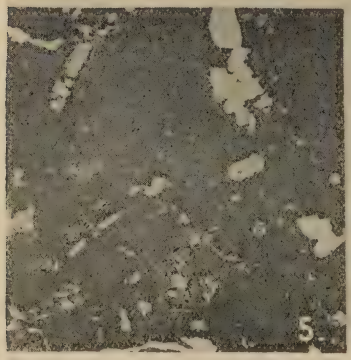

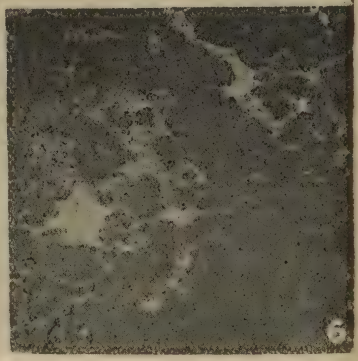

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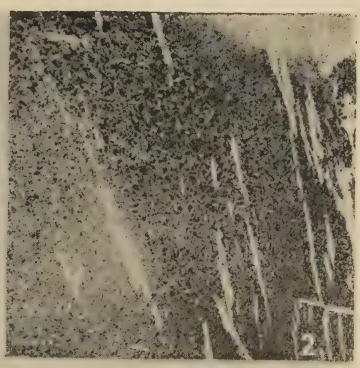

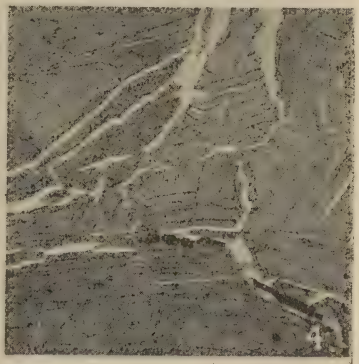

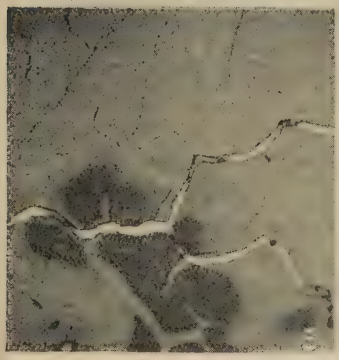

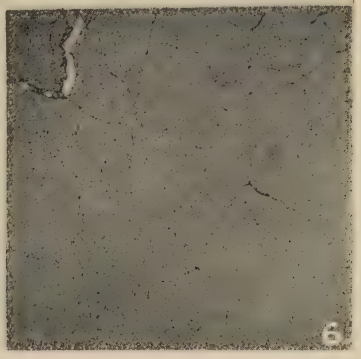

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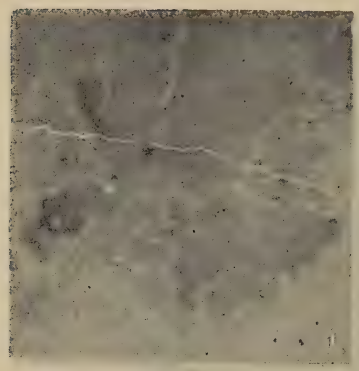

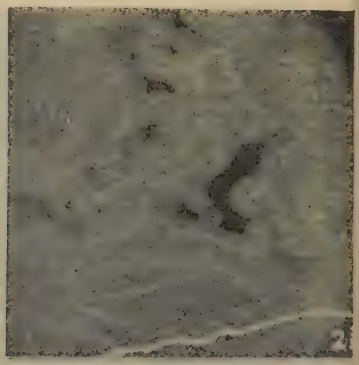

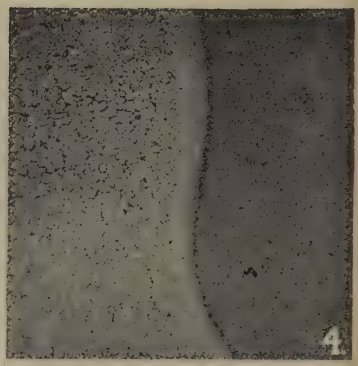

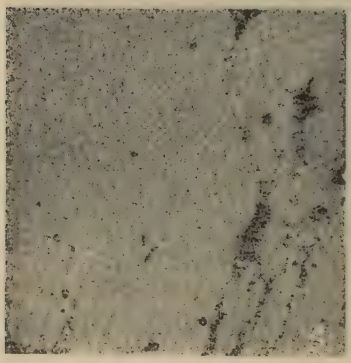

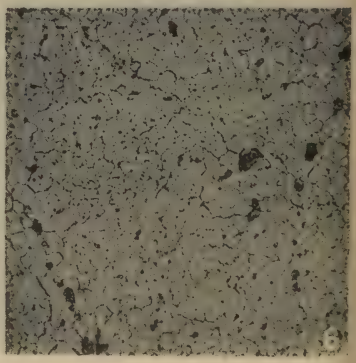

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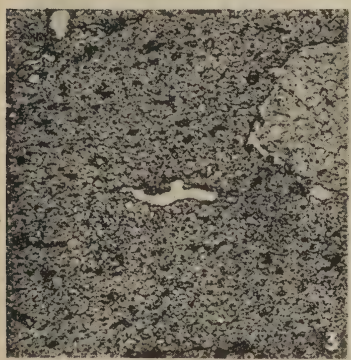

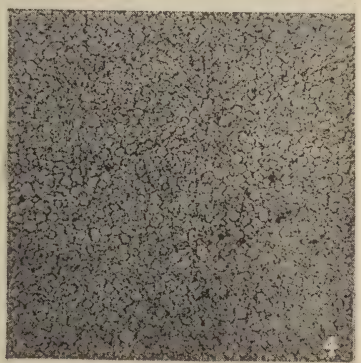

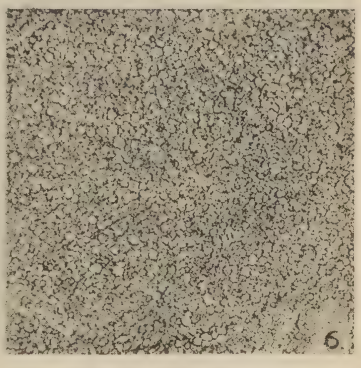

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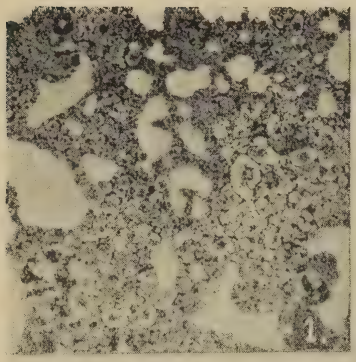

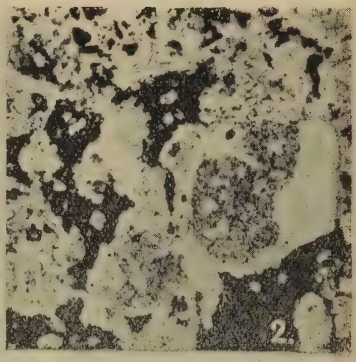

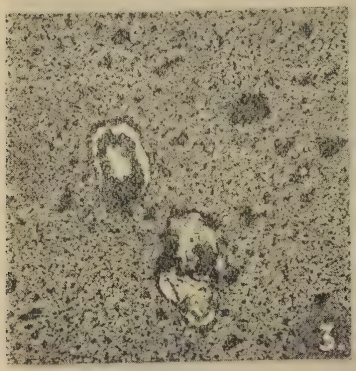

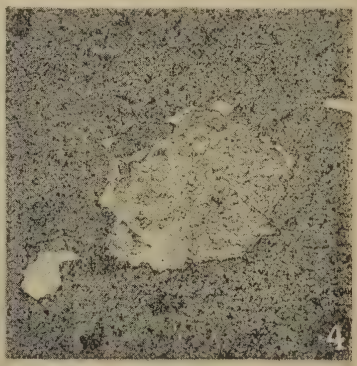

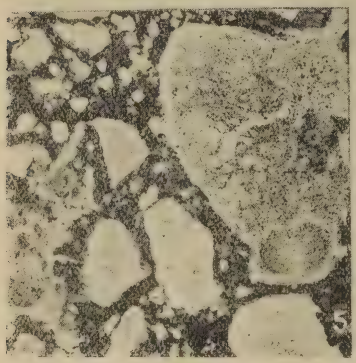

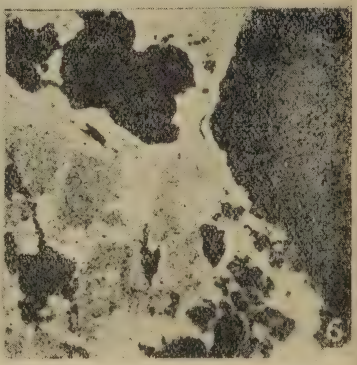

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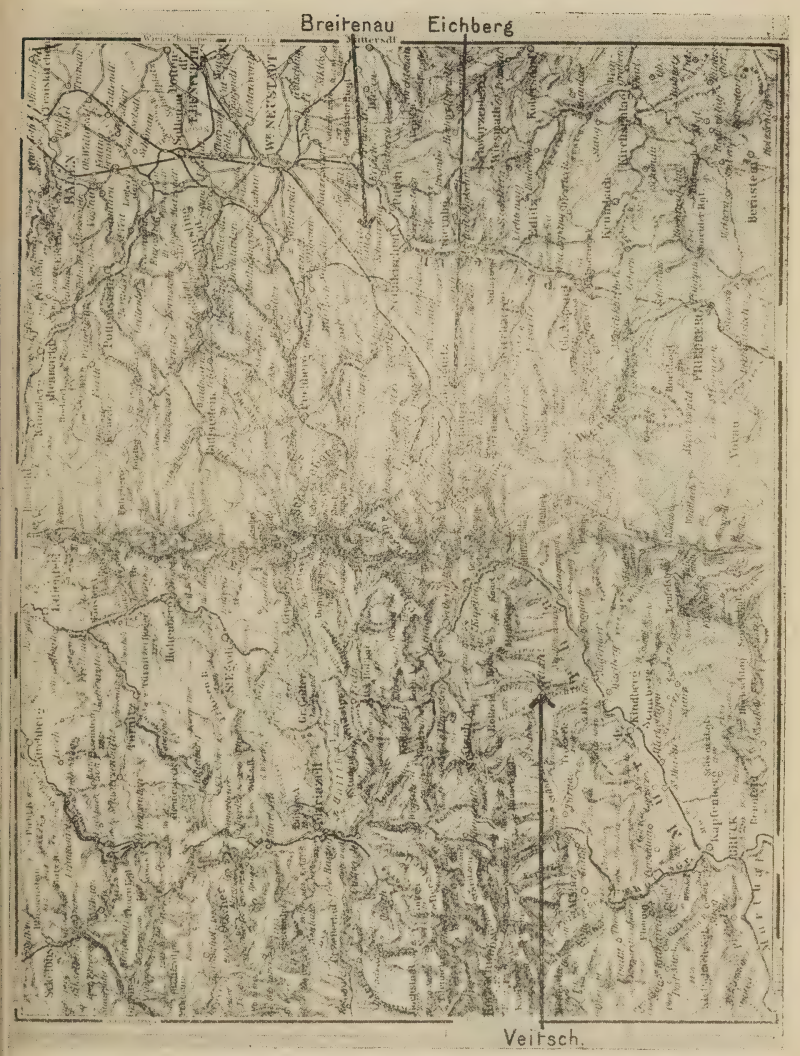

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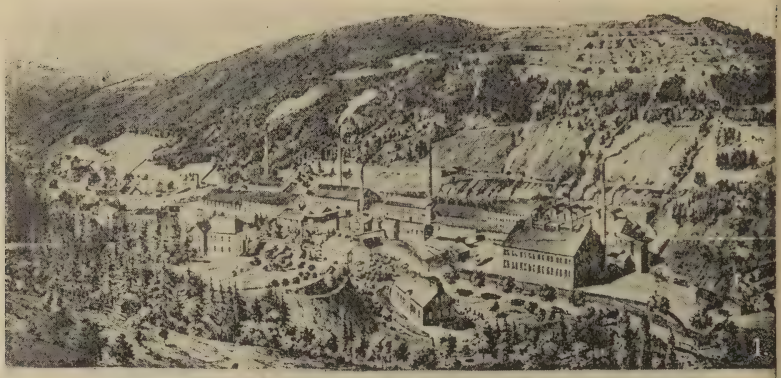

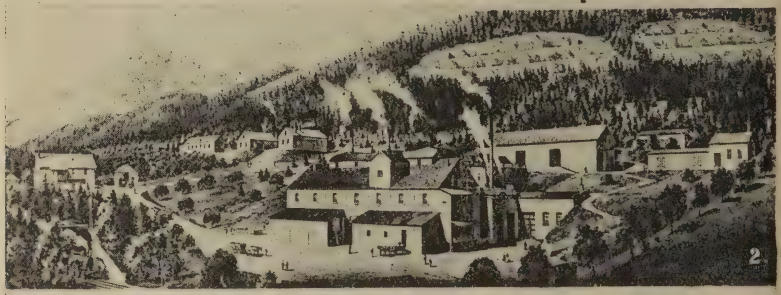

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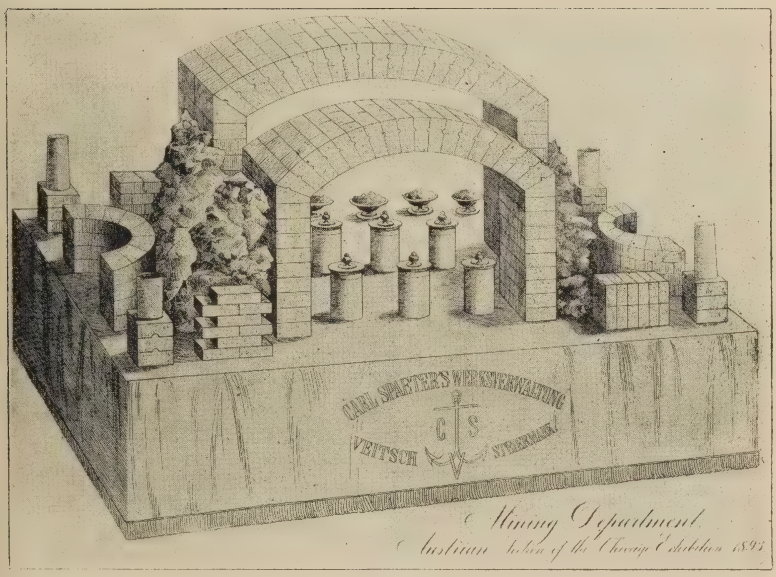
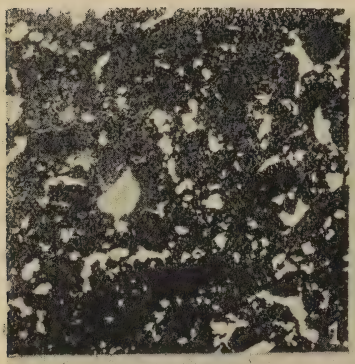
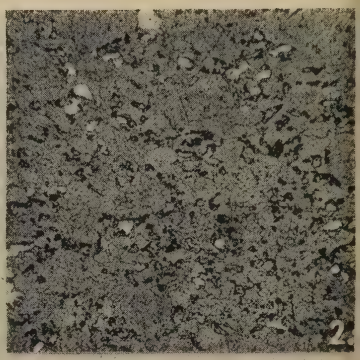
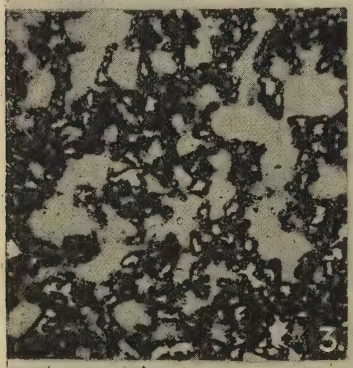
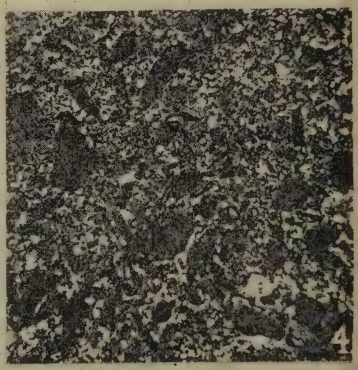

CARL SPARTER'S WERKSVERWALTUNG
C S
VEITSCH STEIERMARK
Mining Department.
Austrian Section of the Chicago Exhibition 1893

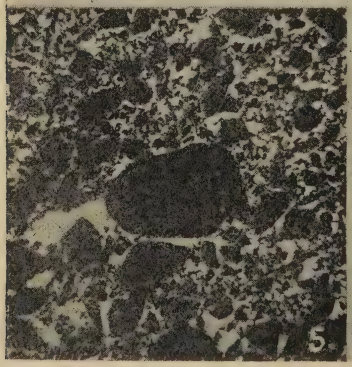
Pl. IX.

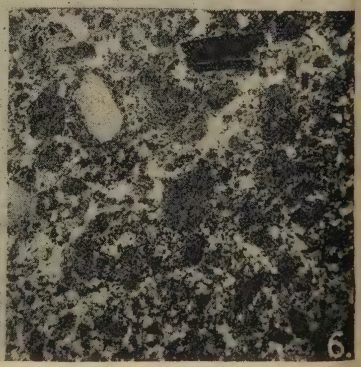












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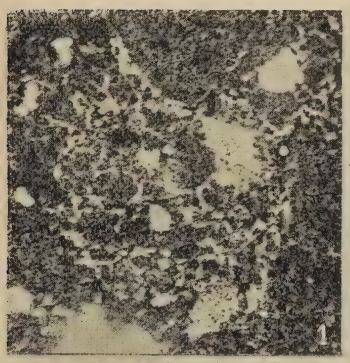

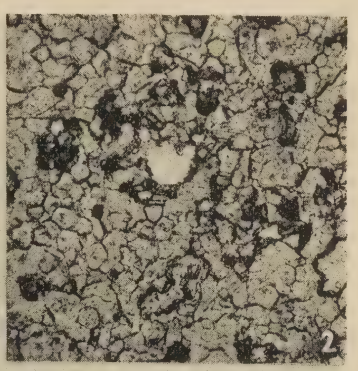

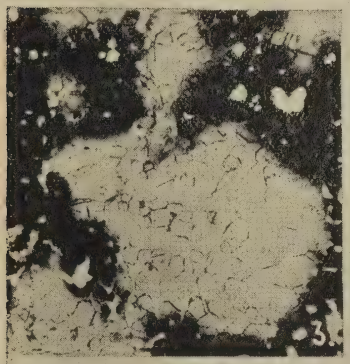

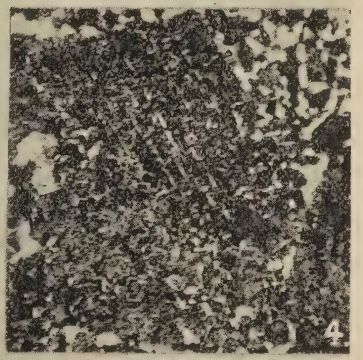

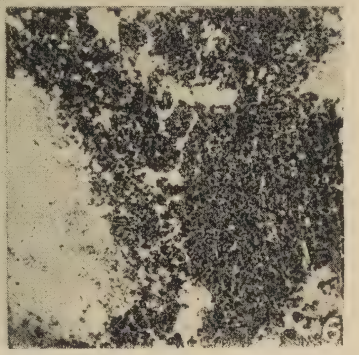

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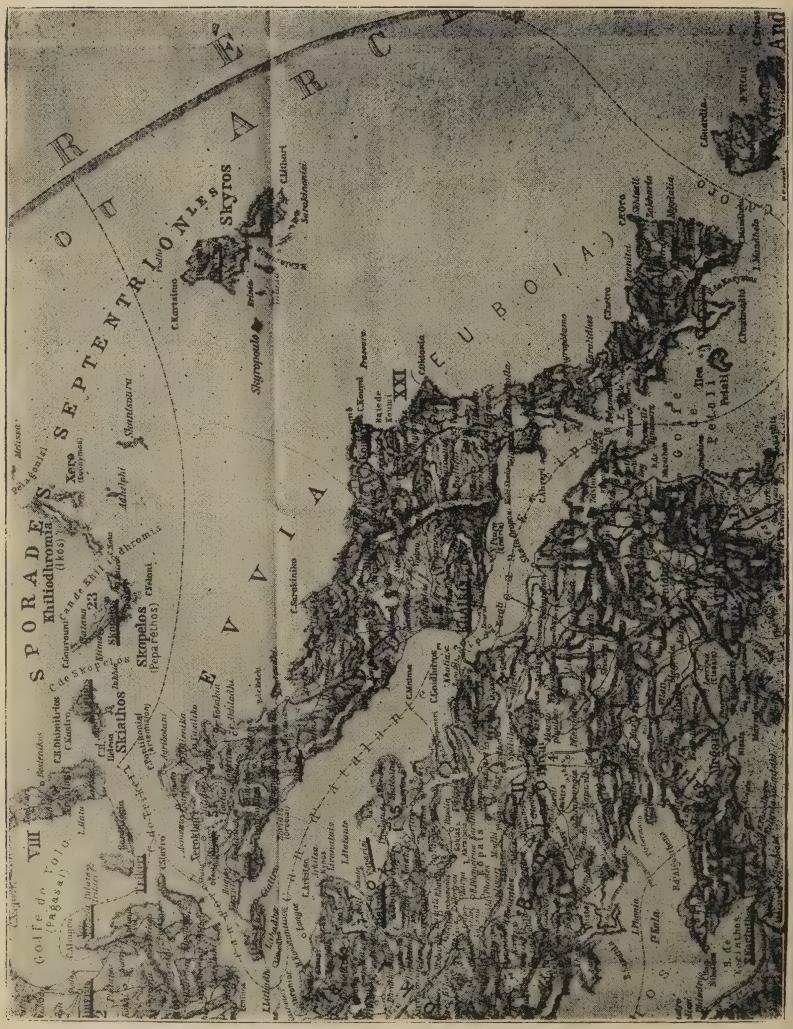
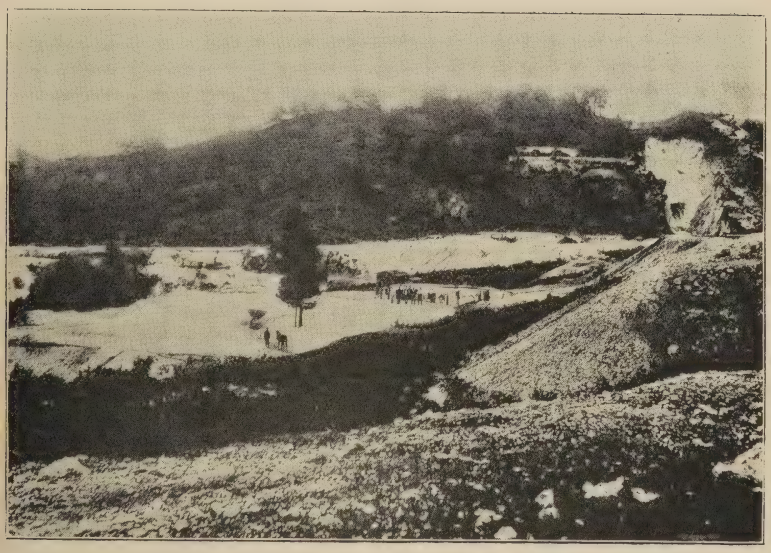

SPORADES SEPTENTRIONALES
Skyros
Khiliodhromia
Skiathos
Skopelos
(Pepa Pétros)
Xero
Skantzura
Adelphi
Golfe de Volo
(Pagasai)
Golfe de Pélasgie
(Pelasgicus)
EUBOIA
Chalkis
Thebes
Lamia
Larissa
Volo
Pelion
Ossa
Olympos
Thermopylae
Tempe
Pharsalos
Karditsa
Trikala
Kalambaka
Meteora
Lake Kopais
Lake Trichonis
Lake Vistonis
Lake Ismaris
Lake Pamvotis
Lake Kerkini
Lake Doiran
Lake Ostrovo
Lake Prespa
Lake Ohrid
Lake Dojran
Lake Tahinos
Lake Volvi
Lake Koronia
Lake Langaza
Lake Vegoritis
Lake Pikrolimni
Lake Kastoria
Lake Mikri Prespa
Lake Ioannina
Lake Trichonis
Lake Kopais

Pl. XIII.

Pl. XIV



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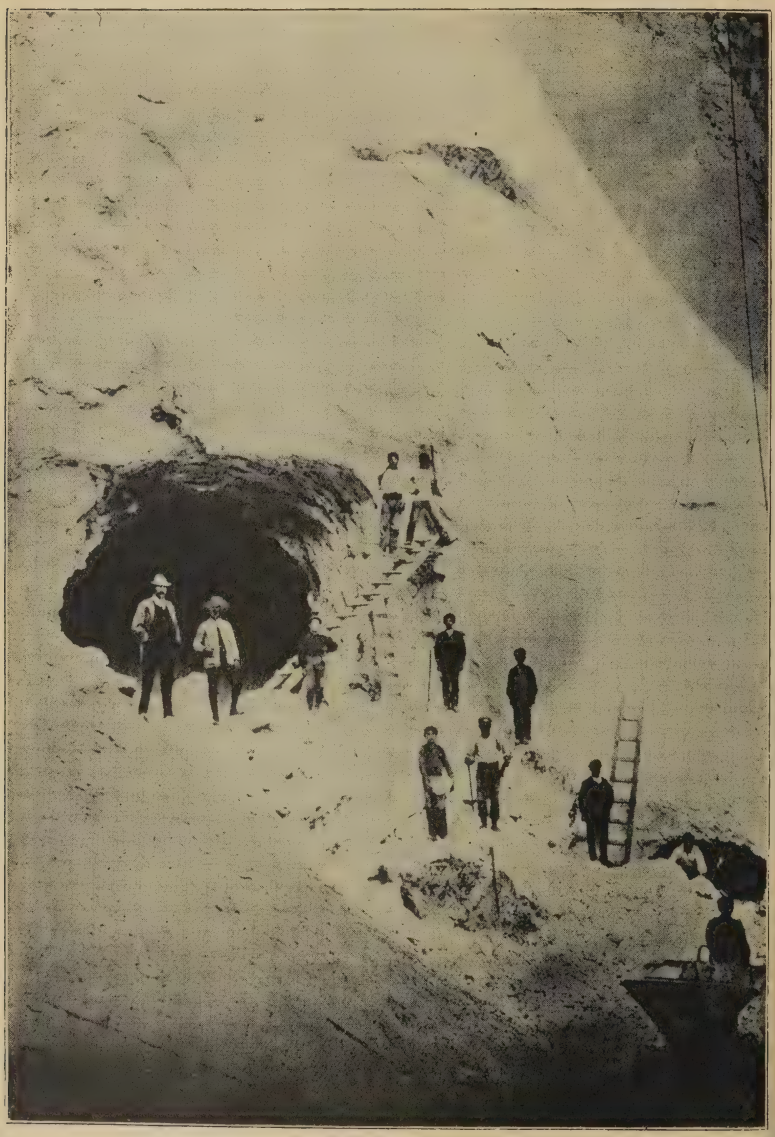
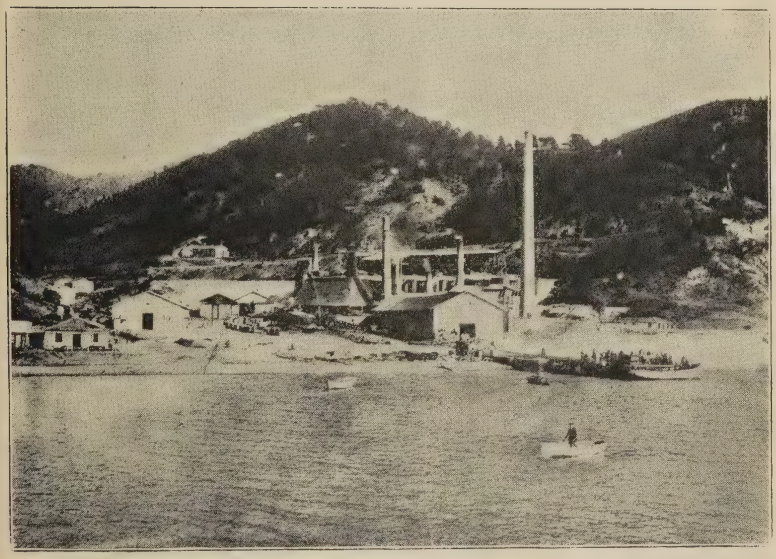


Pl. XVI.

Pl. XVII.

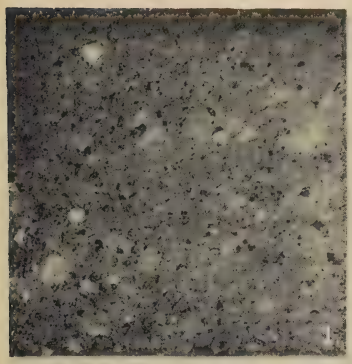
Pl. XVIII.

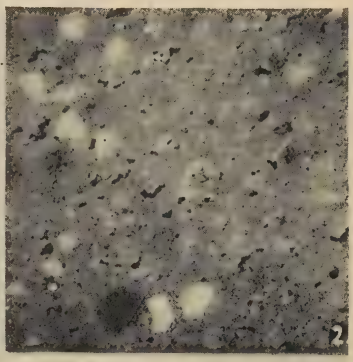


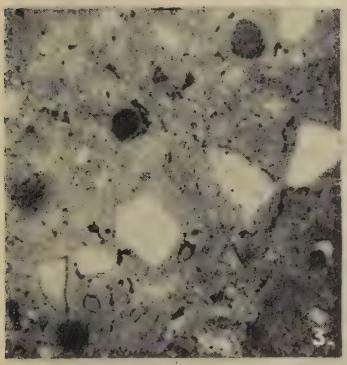
Pl. XIX.

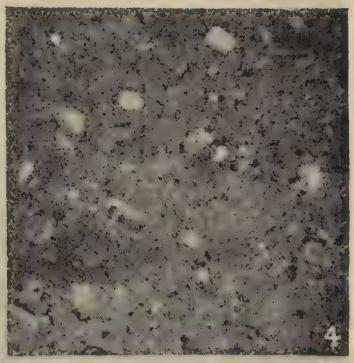
HAGHIA ANA
CALCINATION PLANT
KYMASSI
MANDUDI
DAPHNOPOTAMOS
IPSILYARAKI
LIMNI
LIMNI
ATALANTOS
CEVIDAKIA
STAVROS
PYLI
CALCINATION PLANT
ST JOHN
ADRALEE
HORTOCOPE
ARCHANGELOS
MORAITIS
KAKAVOS
MACCAS
PEFTELI
STRONGYLI
TRUPI VILLAGE
TRUPI
YEROREVMA
PLAKARIES
AGHIA TRITI
ATALANTA CHANNEL
EUBŒA
REFERENCES
SERPENTINE
VILLAGES
CALCINATION PLANTS
MINES AND QUARRIES
RAILWAYS
ROPE-WAYS
ROADS
LIMESTONE
CHALCIS
GEREKARI
CALCINATION PLANT
AFRATI
LEFKANDI
EURIPO CHANNEL.

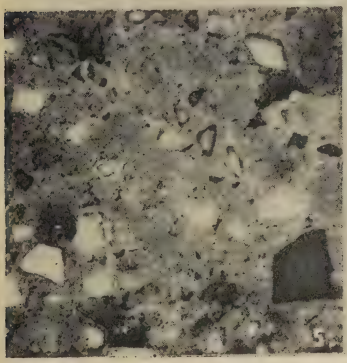
Pl. XX.

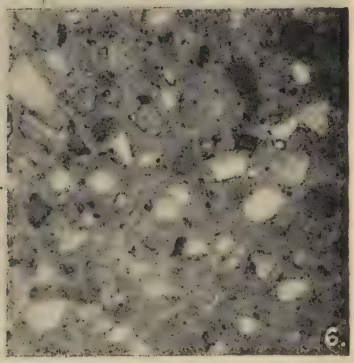












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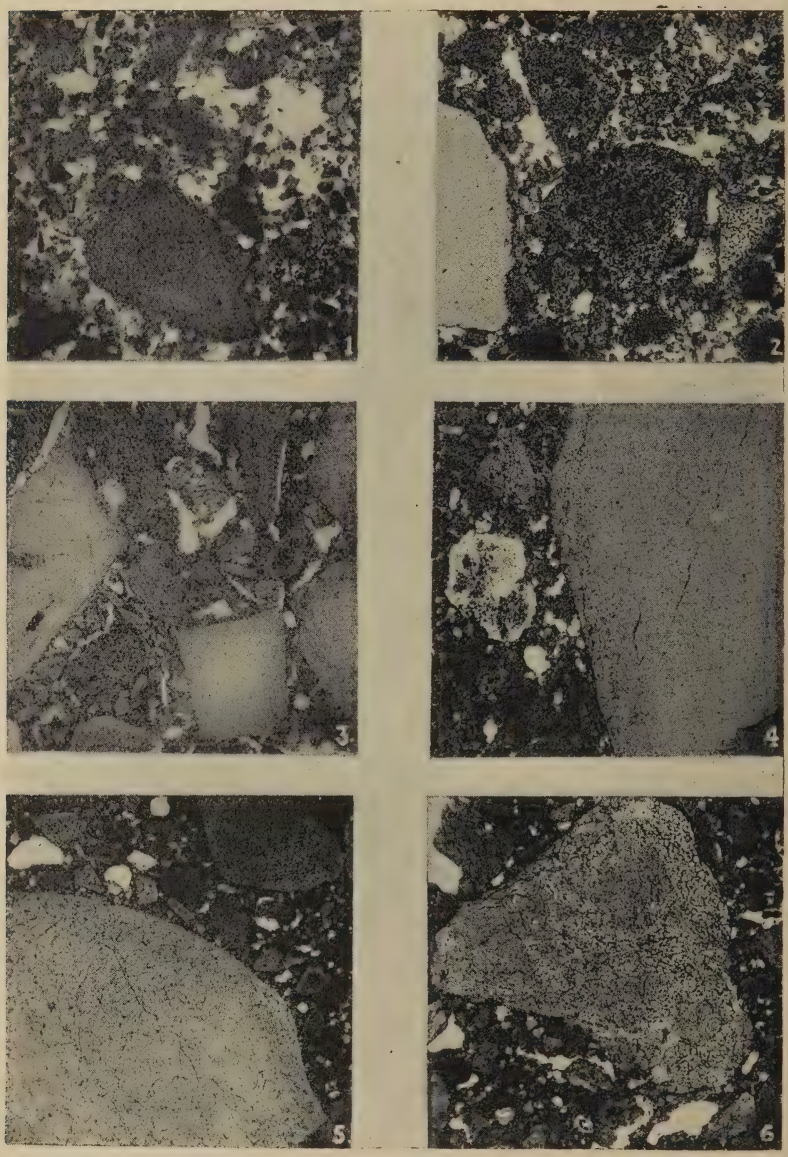

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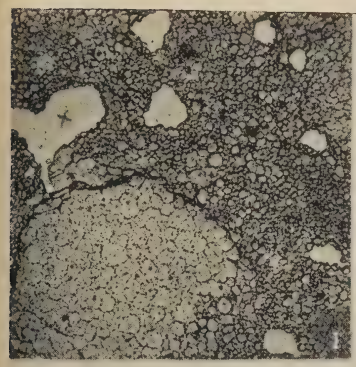

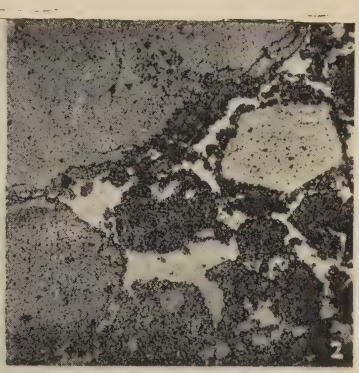

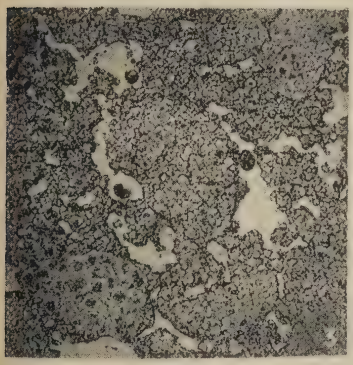

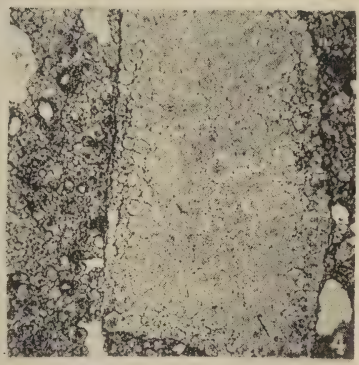

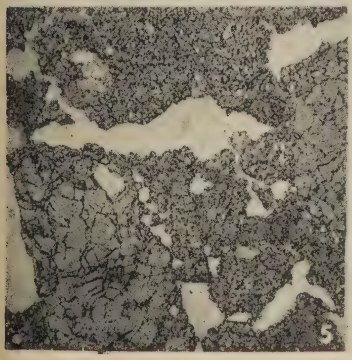

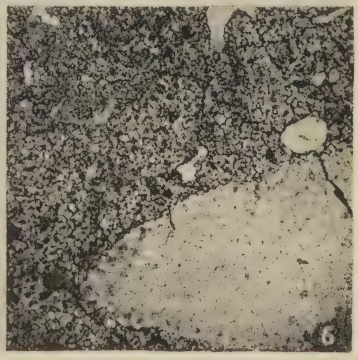

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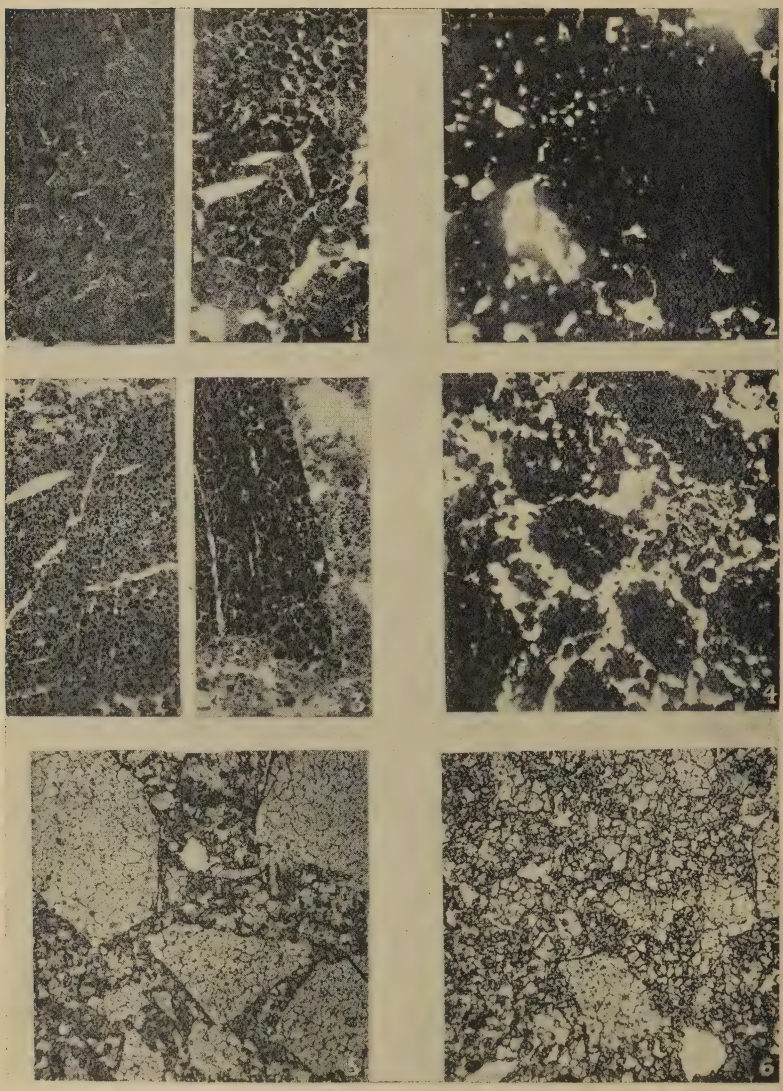

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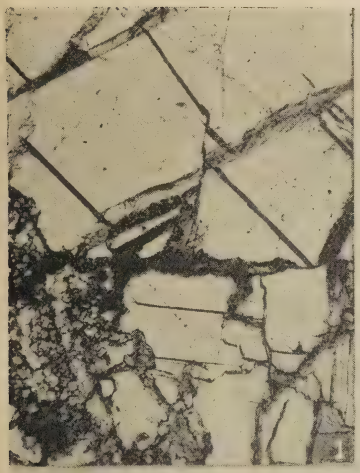

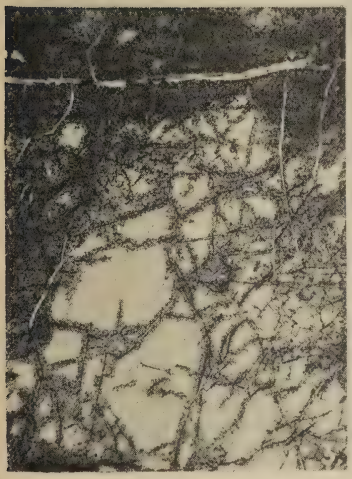

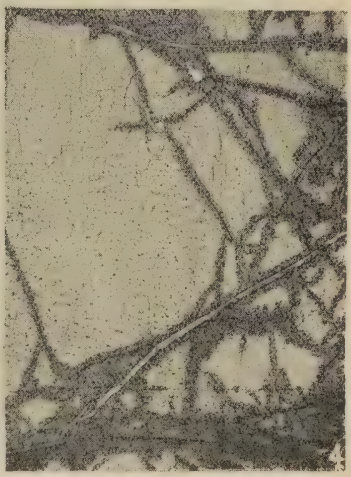

Pl. XXV.

LIEUTENANT SIDNEY ARTHUR GRIMWADE.

LIEUTENANT SIDNEY ARTHUR GRIMWADE.

OUR Society has suffered another severe loss through the death on the 4th August of Sidney Arthur Grimwade, as the result of a flying accident in England, at the early age of 23.

Sidney Grimwade was educated at the Newcastle High School and at Wellington College, Shropshire, and demonstrated the efficiency of his training by passing in the first division at the London University Matriculation Examination when he was only 16, that is, as soon as he was eligible to sit for that examination. A year later he went to join his father at Winton Pottery and at the works of the Atlas China Company, at the same time continuing his education on the technical side at the Stoke Pottery School, under Dr. J. W. Mellor. Here also he distinguished himself by gaining First Class Honours in Pottery with the Silver Medal, awarded as the results of the examination at the close of the Session 1913—14.

In succession to his elder brother, Mr. C. D. Grimwade, he served for a short period as Assistant Secretary to the Society, only relinquishing the post to join the Army. In September, 1914, he enlisted in the 5th North Staffords, along with other old boys of Newcastle High School. Later he was gazetted Second-Lieutenant, and was afterwards drafted to Ireland, where he served during the abortive rebellion. Whilst still in Ireland he was promoted to full Lieutenancy, and then went to France, where he served six months in the trenches, being afterwards invalided home with trench fever.

Lieut. Grimwade volunteered for the Royal Naval Air Service—now merged with the Royal Flying Corps in the Royal Air Force—and when convalescent was accepted in November, 1917. In June, 1918, he was gazetted Lieutenant, though at the time of his death he had not received his "wings" as a pilot.

Lieut. Grimwade had been flying about three months, and displayed exceptional aptitude for the work, being regarded by competent judges as a very skilful pilot. Only three weeks before the fatal mishap his father witnessed an exhibition of flying, in the course of which Lieut. Grimwade looped the loop and nose-dived.

His was an attractive personality, and he had to all appearance a promising future before him. Those who are left to deplore his early loss will know that bright memories of him remain. J. A. A.

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ABSTRACTS.

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Introduction.

THE following are abstracts from papers connected with the clay, refractories, and glass industries in the more important foreign journals as well as those of our own country. The abstracts are arranged roughly in thirteen classes. The groups are constantly overlapping, and, to avoid repetition, a copious index is appended. This will enable any reference to be quickly found. Most of the journals quoted are permanently filed so that the full papers may usually be consulted by members of the Society. Full translations of any of the foreign papers can be obtained at a small charge. As a rule the abstractor indicates the "subject title" of those articles which, in his opinion, contains either no original matter, or matter not suitable for abstraction.

These abstracts were made possible by a grant from the Joint Committee of Allied Pottery Manufacturers, and were compiled by Mr. J. A. AUDLEY, B.Sc. (with the exception of a few initialled).

The following particulars respecting patents may be of use to members :—

Country	Address	Cost
Britain ...	Patent Office, London	Sixpence (extra postage outside United Kingdom)
United States	Patent Office, Washington	Five cents
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In ordering a copy of a patent, the number of the patent and year of the patent, the name of the patentee and the subject of the invention should be stated.

Titles of Journals Abstracted, with Abbreviations.

Amer. Pot. Gaz. ..... "American Pottery Gazette" (American)
Brick ..... "Brick and Clay Record" (American)
Brick Pot. Tr. J. ..... "Brick and Pottery Trades Journal" (British)
Brit. Claywr. ..... "British Clayworker" (British)
Bull. Imp. Inst. ..... "Bulletin Imperial Institute" (British)
Cement Eng. News. ..... "Cement and Engineering News" (American)
Cer. ..... "La Céramique" (French)
Claywr. ..... "Clayworker" (American)
Deut. Töp. Zie. Ztg. ..... "Deutsche Töpfer- und Ziegler- Zeitung" (German)
Diamant ..... "Diamant Glas-Industrie Zeitung" (German)
Feuerung ..... "Feuerungstechnik" (German)
Glash ..... "Die Glashütte" (German)
Glas-Ind. ..... "Die Glas-Industrie" (German)
J. Soc. Chem. Ind. ..."Journal of the Society of Chemical Industry" (British)
Kalk. Schm.-Ztg. ..... "Kalk-, Gips- und Schamotte-Zeitung" (German)
Ker. Rund. ..... "Keramische Rundschau" (German)
Silik.-Zeits. ..... "Silikat-Zeitschrift" (German)
Min. Min. ..... "Mines and Minerals" (American)
Monit. Cer. Ver. ..... "Moniteur de la Céramique et la Verriere" (French)
Pat. J. ..... "The Illustrated Official Journal (Patents)" (British)
Pot. Gaz. ..... "Pottery Gazette" (British)
Pot. Glass ..... "Pottery and Glass" (American)
Pot. Glass. Rec. ..... "Pottery and Glass Record" (American)
Quarry ..... "Quarry" (British)
Sprech. ..... "Sprechsaal" (German)
Tonind. Ztg. ..... "Tonindustrie-Zeitung" (German)
Tonwaar. Ind. ..... "Tonwaaren Industrie" (German)
Tonwar. Ofen. Ztg. ..... "Tonwaren-Ofen und Töpfer Zeitung" (German)
Tonwar. Fab. ..... "Tonwarenfabrikant" (German)
TRANS. ..... "Transactions of The Ceramic Society" (British)
Trans. Amer. Cer. Soc. .."Transactions of the American Ceramic Society" (American)
Zentr. Zieg. ..... "Zentralblatt für Glas-, Porzellan-, und Ziegelindustrie" (Austrian)

Also a number of other Journals not devoted exclusively to Pottery and Clays.

There is a difficulty in procuring some Continental Journals; and some have ceased publication while the war is on.

*** The first number represents the number of the volume, the last the year of publication, and intermediate numbers the page or pages where the subject is discussed.

Abstracts.

I.—RAW MATERIALS.

ALUMINIUM NITRIDE.—Soc. Générales des Nitrures (*Pat. J.*, No. 1,422, 1916). Pat. No. 24,533, Dec. 24th, 1914. Process for preparation.

MAKING ARTICLES FROM NITRIDES.—E. Podszus (*Pat. J.*, No. 1,413, 1916). Pat. No. 21,378, Oct. 22nd, 1914. Coherent bodies of nitrides of boron, titanium, zirconium, aluminium, etc., may be obtained. The nitride bodies produced may be thin objects such as tubes, threads, etc., or crucibles, or may be used in the construction of furnaces. They do not conduct the electric current.

SILICA.—R. G. Varcoe (*Pat. J.*, No. 1,486, 1917). Pat. No. 106,232, Nov. 22nd, 1916. The residue of quartz left after extracting china clay from china stone is sieved to separate sand, etc., ground, levigated, or washed, and dried, to obtain a filling for paper, textile materials, etc. Alumina or china clay may be added.

BORAX.—Deutsche Gold and Silber Scheideanstalt vorm. Rœssler (*Pat. J.*, No. 1,490, 1917). Pat. No., 107,019, June 7th, 1917. Relates to the production of borax from mixtures of borax or boric acid and sodium sulphate by dissolving the material, adding soda if necessary, and evaporating the nearly saturated solution at its boiling point until most of the sodium sulphate has separated out. The solution is then cooled, preferably to 34° C., to crystallize the borax.

PHOSPHATES.—C. G. Memminger (*Pat. J.*, No. 1,490, 1917). Pat. No. 107,082, June 28th, 1916. Natural phosphates (of calcium) containing silica and calcium carbonate are calcined at 1,400—1,500° C. to drive off volatile matter and decompose the calcium carbonate, yielding lime, which combines with the silica. For successfully carrying out the invention there must be enough silica present to combine with the lime. The tricalcium phosphate is not affected. Specifications 15,237/87, 22,851/10, 13,891/11, and 16,335/14 are referred to.

TREATING CLAY, ETC., FOR DISCOLORATION.—W. Feldenheimer and W. J. Gee (*Pat. J.*, No. 1,425, 1916). Pat. No. 894, 1915. Discoloration due to impurities is nullified by treatment to convert a portion of the impurities into a colouring agent which neutralizes the discoloration produced by the unaltered impurities. The yellow discoloration of china clay is nullified by treatment with a dilute solution of potassium (or sodium) ferrocyanide, and so converting some of the iron present into prussian blue.

TREATING CLAY.—W. Feldenheimer (*Pat. J.*, No. 1,500, 1917). Pat. No. 108,808, Aug. 11th, 1916. Addition to 106,890. In washing or cleaning clay according to the invention described in the parent specification, a solution of sesquicarbonate of sodium, of carbonate of ammonium, or of carbonate of potassium, is used in place of carbonate of sodium.

WASHING CLAY, ETC.—Graf Schwerin (*Pat. J.*, No. 1,454, 1916). Pat. No. 11,659, Aug. 12th, 1915. Clay or kaolin is deposited from its suspensions in water and separated from its impurities by allowing it to settle while in the soluble condition, for example, by adding to the suspension a small amount of caustic soda lye, sodium silicate solution, or other basic electrolyte.

TREATING CLAY.—W. Feldenheimer (*Pat. J.*, No. 1,489, 1917). Pat. No. 106,890, July 10th, 1916. In washing and cleaning clay, particularly china clay, a dilute solution of sodium carbonate is used in place of water to facilitate the deposition of the mica and other impurities from the clay in suspension as it passes over the mica drags. After the clay has passed over the mica drags, it may be passed to a settling tank where a further quantity of "mica" is deposited, and afterwards to a depositing chamber where the deposition of the clay is facilitated by the addition of an acidifying agent such as commercial alum or sulphuric acid sufficient to neutralize the alkalinity of the suspending liquid.

SEPARATING CHINA CLAY, ETC.—W. J. Gee (*Pat. J.*, No. 1,421, 1916). Pat. No. 24,077, Dec. 15th, 1914. China clay, ochre, and similar materials are graded and separated from liquids in which they are suspended, by passing the material first through a preliminary centrifugal apparatus, running at a relatively low speed, for eliminating the coarse or heavy grades, and afterwards through a second centrifugal apparatus in which the separation or grading is completed. Specification 4,155/07 is referred to.

DRYING CLAY.—C. Battiscombe, N. O. Walker, and G. L. Bates (*Pat. J.*, No. 1,465, 1917). Pat. No. 102,784, May 11th, 1916. China clay is dried in a thin layer on one or more travelling bands in a closed chamber heated by steam pipes and exhausted by a pump. The apparatus is shown in an illustration.

DRYING CHINA CLAY.—T. M. Stocker (*Pat. J.*, No. 1,494, 1917). Pat. No. 107,866, Aug. 31st, 1916. China clay is dried on a floor heated by the gases from one or more furnaces passing through a series of flues beneath it, the air for the furnaces being previously heated. The air for the furnaces is drawn with the moisture from the drying clay through a collector and through heating passages beneath the flues to the ash-pit. Heated air also is supplied above the fire through passages tortuously arranged in the roof.

ALKALI SILICATES.—E. A. Paterson (*Pat. J.*, No. 1,446, 1916). Pat. No. 8,752, June 14th, 1915. Alkali silicates containing a high proportion of silica are hydrated so as to render them soluble in water, by mixing the silicate with water or dilute silicate solution and treating with steam under pressure. The quantity of water employed is given as 40—50 per cent., the excess water being evaporated by the steam, but the steam may provide additional water if necessary. The pressures mentioned are 100 lb. per sq. in. or lower, preferably 55 to 75 lb. per sq. in. The material swells and becomes porous, and may contain as much as 19 per cent., or as little as 6 per cent. water.

POTASSIUM FROM FELSPAR, ETC.—C. W. Drury (*Pat. J.*, No. 1,467, 1917). Pat. No. 15,432, Nov. 2nd, 1915. Felspar or other potash-bearing silicate rock is treated to render the potassium available for fertilizing purposes by heating the rock with calcium oxide or carbonate and iron oxide, to obtain a fused or sintered product and to form a complex silicate insoluble in water but decomposable by weak acid. The heating may be carried out in a blast furnace. Either ferrous oxide, or a mixture of ferric oxide and carbon may be used. The product may be treated with weak acids to separate potash and alumina.

ALKALIES FROM SILICATES.—A. H. Cowles (*Pat. J.*, No. 1,493, 1917). Pat. No. 107, 640, July 4th, 1916. A furnace charge comprising silicates such as felspar, leucite, zeolites, clay, etc., or artificial alkali-aluminium silicates with an alkaline earth compound such as lime, calcium carbonate, or calcium chloride and, if necessary, an alkali such as sodium carbonate, is so made up that after sintering the product shall contain two molecules of alkaline earth oxide to each molecule of silica and less than two but preferably more than one molecule of alkali oxide to each molecule of alumina. The sintered product may be used as a fertilizer, or may be leached with water, etc. Specifications 10,093/87, 5,296/92, and 20,220/02, and U.S. Specification 382,505 are referred to.

ALKALI COMPOUNDS FROM SILICATES.—B. V. Halvorsen (*Pat. J.*, No. 1,490, 1917). Pat. No. 107,012, May 13th, 1917. Alkali-aluminium silicates such as felspar, mixed with calcium cyanamide, are heated with water (above 100° C. under pressure) or superheated steam (above 650° C.) with or without the addition of salts such as chlorides, nitrates, or sulphates. Ammonia is liberated and some of the alkali and alumina is rendered soluble.

ALKALI SILICATES.—R. M. Caven (*Pat. J.*, No. 1,486, 1917). Pat. No. 106,247, Jan. 17th, 1917. A solid hydrated soluble alkaline silicate is produced by mixing pulverized alkaline silicate with from 25 to 38 per cent. of water and heating the mixture to a temperature above 70° C. but preferably below 100° C. ; but when the higher proportion of water is used the temperature may exceed 100° C. Specification 9,730/98 is referred to.

ALKALI SILICATES.—R. M. Caven (*Pat. J.*, No. 1,497, 1917). Pat. No. 108,372, Aug. 21st, 1917. A solid hydrated soluble neutral alkali silicate is produced by mixing pulverized neutral silicate with from 25 to 38, or, according to the Provisional Specification, about 20 per cent. of its weight of water and heating the mixture under atmospheric pressure to a temperature above 70° C. and preferably below 100° C., but when the higher proportion of water is used the temperature may exceed 100° C. Specification 9,730/98 and the corresponding German Specifications 103,407 and 108,400 are referred to.

ALKALI SILICATES.—J. W. Spensley and J. W. Battersby (*Pat. J.*, No. 1,498, 1917). Pat. No. 108,576, Sep. 29th, 1916. Addition to 11,959/14. In the production of readily soluble alkali silicates by the wet-grinding process described in the parent Specification, the liquid product, before being allowed to solidify, is subjected to heat, the heating being uniform and within the range 100—170° F. The material may be run into trays and then heated as by hot water or steam or in a stove, or may be spread on a heated surface such as a rotary drum. Evaporation may be prevented by maintaining a wet atmosphere. The apparatus is figured for one mode of treatment.

PURE ZIRCONIUM OXIDE.—K. Leuchs, Ger. Pat. 295,246, Aug. 1st, 1915. Addition to Ger. Pat. 285,344. Crude zirconium oxide is dissolved in hydrochloric acid. To the solution is added sulphuric acid in the proportion $2H_2SO_4 : 3ZrO_2$, and the mixture is allowed to stand in the cold or at 40° C. Zirconium sulphate separates in small prisms, which are free from iron and titanium.

REFINING CLAY.—S. A. W. Okell, U.S. Pat. 1,222,979, April 17th, 1917. Raw clay is suspended in water, and continuously fed into the bottom of a drum where paddles attached to a vertical shaft give it a strong centrifugal movement. The grit and other heavier particles are removed in suspension from the lower part of the drum. The purified clay passes out through a vertical tube, with a side outlet, at the top of the drum.

II.—THE PHYSICAL, CHEMICAL, AND OTHER PROPERTIES OF RAW AND FINISHED PRODUCTS. TESTING.

QUARTZITES AND SILICA BRICKS.—Friedrich Wernicke (*Stahl und Eisen*, 33, 235, 1913). After pointing out that the appropriate technical journals had rarely published articles on refractory materials, the author refers to several papers which had recently appeared in *Stahl und Eisen*, by Dr. O. Lange "On Silica Bricks for Martin Furnaces" (32, 1,729, 1912), by Professor Grum-Grzimailo on the "Disintegration of Dinas Bricks" (31, 224, 1911), and by Dr. Endell on the "Constitution of Dinas Bricks" (32, 392, 1912).

The two last named are stated to be of great scientific interest, and the concluding remarks or Dr. Endell are held to be of value for actual practice, but the producer of refractory bricks cannot yet make much use of the results for his own purposes. To the metallurgist it is a matter of indifference whether the quartz of his silica bricks is gradually transformed under the influence of the high temperature of the furnace into the to him probably very little known tridymite or cristobalite, both of which occur extremely rarely in nature; he only requires the longest possible durability for his bricks, and therefore the employment in their production of the raw materials best suited for that. The producer of silica bricks cannot wait for the results of protracted trials in the works, in order to know how the raw material worked up by him later than the finished brick in the furnace will stand the test, but he must start from the raw material, and therefore he has an interest in regard to it, a process to become acquainted with, by which he can investigate the suitability and accurately estimate the value of his quartzite before further working up, for he must at once produce security for the excellence of his products. Professor Grum-Grzimailo draws the conclusion that good silica bricks with more than 94 to 95 per cent. silica can be produced from every quartz material, just as good from authigenous, *i.e.*, crystalline quartzes and quartzites found on primary deposits—gang-quartzes and palæolithic quartzites—as from allothigenous, *i.e.*, clastic (tertiary) quartzites found on secondary deposits; this conclusion the author cannot endorse according to his own experiences. If the author's investigations in reference to this had been known to him in time, or could have been tested by him, then perhaps the Professor would not have pronounced this opinion. Its correctness must first be proved by very searching trials in the furnaces of the smelting works. But if in this way it becomes confirmed, then will the hitherto existing mode of production of silica bricks be thereby considerably modified. The good tertiary "Findlingsquartzite" (that is, quartzites which have been transported and reconstituted elsewhere) now found in comparatively small extent and therefore of costly occurrence, will then suffer a very considerable depreciation. The remark of Dr. Endell, on the other hand, that quartzites which in microscopical examination show in the individual quartz-grains a wave-like extinction (in turning the stage the colour of the single quartz-grains is not extinguished uniformly in its whole surface, but it slips away wave-like over the surface), are useless for the production of silica bricks, confirms the author's earlier published observation that this appearance is seen particularly in the palæolithic quartzites, which have been exposed to a strong ground pressure, and which on account of their microstructure the author designated as useless, whereas the wave-like extinction is scarcely to be observed in the good tertiary quartzites. Endell's view that the dynamic pressure of the rock-strata is the reason why such grains fall to dust on being heated, must be accepted as correct. Probably through the strong ground pressure stresses arise in the quartz grains, which are released at a higher temperature and cause the disintegration of the grains. For this reason also the conclusion of Professor Grum-Grzimailo is found to be erroneous.

Dr. Lange (of Hörde) is stated to be in the enviable position of being at the same time producer and user of his own refractory bricks. When in the following the author agrees with Dr. Lange, it is only to supplement from his own experience what Dr. Lange has said, in the hope of further interesting metallurgists and stimulating discussion.

The author has for a year endeavoured to find a process for investigating the suitability of quartzite for making silica bricks, after he had arrived at the conviction that chemical and pyrometrical investigation offered no reliable support for the valuation of quartzite. He has found this process in the rapid and not at all elaborate microscopic investigation, and reported exhaustively on it in collaboration with Dr. Wildschrey (of Bonn) in a pamphlet published by the *Tonindustrie-Zeitung*. "The investigation of Quartzite and Determination of its availability as a Refractory, particularly for the Production of Dinas Bricks." He believes the correctness of his view concerning the chemical and pyrometrical investigation not sufficing, to be confirmed by

analyses published by Dr. Lange, which he has himself supplemented by many others. The calculated average values for all these is as follows:—

	SiO_2	Al_2O_3	Fe_2O_3	CaO
I. North-eastern slope of the Siebengebirge (near Bonn)	97·27	1·48	0·40	0·07
II. Westerwald	97·62	1·40	0·37	0·07
III. Quartzite on left of the Rhine ...	98·10	1·30	0·38	0·06
IV. Hessian quartzite	98·30	1·23	0·37	0·12
Average of the 67 analyses	97·82	1·35	0·38	0·08

this last giving the composition of quartzite approved for the production of silica bricks. The calculated averages for useless quartzites obtained in the same way are:

	SiO_2	Al_2O_3	Fe_2O_3	CaO
(*a*) North-eastern slope of the Siebengebirge	96·92	1·86	0·95	0·20
(*b*) Westerwald	97·41	2·19	0·36	0·06
(*c*) Quartzite on left of the Rhine ...	97·27	1·96	0·64	—
(*d*) Hessian quartzite	98·20	1·34	0·32	0·11
Average of the 24 analyses	97·25	1·84	0·57	0·12

this last giving the composition of useless quartzites.

The quartzite from Eudenback (under *a*) had an unusually high iron-content of 3·05 per cent., and that from Selters (under *b*) had an alumina-content of 4·40 per cent., and by excluding these two numbers the respective averages for *a* and *b* would be reduced to 0·54 and 1·82. If comparison be made between I and *c*, II and *b*, III and *d*, IV and *d*, the differences are not worth mentioning, and the same with the two general average compositions.

The melting point of all the above quartzites lies at Seger cone 35 or 36 (about 1,770° and 1,790° C.) with a difference of only 20° C., which plays no important part in such a high temperature, so little indeed, that many good quartzites melt at cone 35, and other useless cones melt first at cone 36.

According to this, one may well say that the results of chemical and pyrometrical examination has little value for our purpose. Even the origin of the quartzite gives no explanation on the question, for beside good tertiary quartzites are found in the same deposits useless quartzites and transitions from the latter to the former, which is obvious by their mode of origin. The microscopic appearance, structure and colour of good quartzite vary somewhat; even the characteristic yellow spots on fractured surfaces are found in useless quartzites sometimes in greater quantity than in the good.

All these distinguishing marks and investigations may easily lead to incorrect conclusions. If on the other hand, a thin section of quartzite is examined under a microscope in polarized light, the desired information is here obtained at once through the picture of the microstructure. Useless quartzites (Fig. 1) always show here a clear uniform picture in which the single quartz grains lie spread out compactly against one another without any amorphous binding material. On the other hand, in all useful quartzites (Fig. 2), the single quartz grains are seen to be separated from one another, lying embedded in an opaque ground mass, the basal cement. At the same time it is seen in ordinary or in polarized light whether the quartzite contains many or few impurities, of what these consist, and whether their quantity is so great that the chemical composition and the melting point will be unfavourably affected thereby, futher whether on this account for safety the chemical and pyrometrical investigation is still worthy of recommendation, or whether the impurities are present in such great quantity that the quartzite must for that reason be condemned without further investigation. The chemical and pyrometrical investigation is therefore only to be undertaken in particular cases to supplement the microscopic, but in most cases it will be superfluous.

The author holds it to be excluded that inclusions of gases or liquids should cause the destruction of rocks in the fire, as has at times been assumed. These inclusions are so small even under the microscope, but the walls of rock

surrounding them of such strength, that the inclusions must develop in the fire quite extraordinary force in order to be able to burst open their prison, and it is not conceivable that such a small quantity should be capable of that result. In relation to the force necessary for this, even the explosive force of dynamite almost seems insignificant.

For undertaking exhaustive microscopic investigation a practised eye is requisite; the author was first obliged to examine for purposes of study a great number of quartzites known to him, until he could make known his results of observations. He has since had occasion to undertake numerous investigations of that kind for people interested in quartzite deposits, and he does not know of a single case in which his opinion given on the basis of microscopic examination has later proved wrong in the employment of the respective quartzites. The quality of a quartzite bed, as far as it is not already perceptible macroscopically to the eye does not so much change, according to

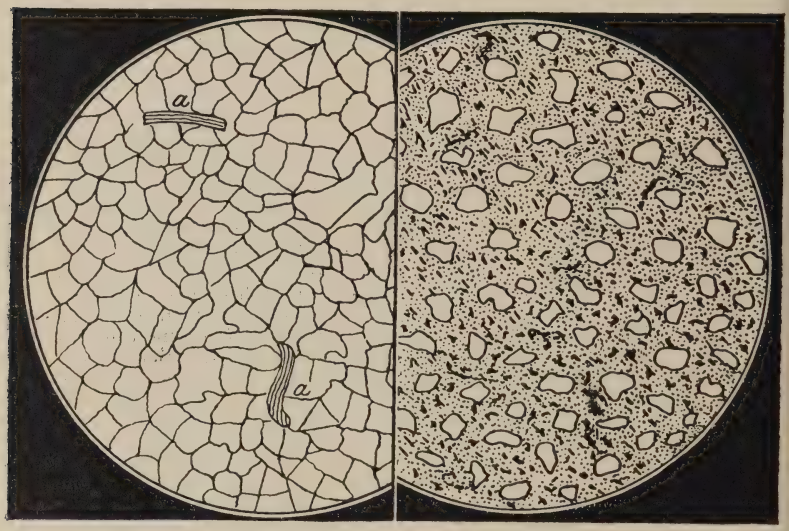

Fig. 1. Useless Quartzite.

Palæolithic quartzite from the Rhenish Devon (so-called Bing quartz). Appearance of section whitish, similar to one of matt glass. In ordinary light under the microscope almost nothing visible. In polarized light are to be seen large authigenous crystalline quartz grains with tolerably sharp edges pushing against one another or indented with one another by jagged edges. *a*, *a* = Muscovite fibres (wanting in tertiary quartzites and therefore characteristic for palæolithic quartzite).

Fig. 2. Useful Quartzite.

Tertiary quartzite from N.E. slope of the Siebengebirge. Appearance of section a not uniformly yellow cloudy mass. In ordinary light under the microscope only appearing at a feebly yellowish brown mass. In polarized light are to be seen smaller allothigenous clastic quartz grains of different sizes and rounded shapes lying single in a fine-grained blackish opaque ground mass, the basal cement (consisting of amorphous silica).

the author's observations, as that the examination of one good hand specimen would not provide sufficient results; for prudence several specimens can easily be examined.

In default of other explanations the view was formerly heard occasionally that good quartzites could only occur in the vicinity of basalts, because here in the eruption of the molten basalt they had already been burnt by nature and therefore would now expand no more in firing. Whoever has once taken

the opportunity to inspect an occurrence of basalt, particularly one so characteristic as that of the Weïlberg near Heisterbach in the Siebengebirge, could convince himself from it that the fire effect of the fluid basalt was restricted to a very narrowly limited zone round the place of eruption. But good quartzites will be found at a greater distance, often many kilometres from the basalt. Not fire has played a part, but water; in the weathering of basalt tuff large quantities of amorphous silica were dissolved and taken up by the mountain waters. These carried the amorphous silica to porous quartz-sand beds, where the silica slowly separated, enveloped the individual quartz-sand grains as the microscope shows it to us, and the "fresh-water quartz" cemented them to a firm rock, which we now make use of as "Findlings-quartzite" for the production of silica bricks.

The burning of the raw quartzite mentioned by Dr. Lange is practised in some factories, in others (and very important ones) discontinued, because they do not regard it as necessary, and the notion is that the burning of the prepared bricks suffices for their further expansion to be reduced to the lowest limit necessary. But the raw quartzite through burning becomes friable and can then be ground more easily; in this way also a greater quantity of dust is formed. This and the possibility of easier grinding is the reason why quartzite is burnt in some places before the further working, whereby the cost of burning is compensated by the smaller wear of machines, the possibility of easier grinding and the smaller costs. Particularly interesting is the statement that a small addition of clay to quartzite should affect the durability of silica bricks not unfavourably, whilst it has to be assumed that the clay must here act as fluxing material. Just as valuable is the statement that with a pressure of 30 atmospheres hydraulically pressed silica bricks have proved excellent. For the assumption that freshly made silica bricks should be dried quickly and as hot as possible there is no warranted ground. The author at a certain works was unable to see any difference in the quality of a brick dried by laying down one part of the brick immediately on a highly heated drying kiln, while another part was dried in an iron frame standing on the drying kiln. With the use of a drying kiln without frames there is also combined a great waste of space and fuel. But the direct firing of a drying kiln is likewise a great waste; at the works just referred to this necessitated an annual expense of £535 for fuel alone, excluding expenses for the fireman's wages. By proper arrangements, these expenses can be completely avoided by heating the drying kilns with waste heat from burning kilns.

A Mendheim gas chamber kiln is only seldom used for burning silica bricks, and is only to be recommended for a very regular working. At the high burning temperature the dividing walls of the kiln chambers, variously pierced by the gas and air channels can be strongly attacked, and from that high repairing costs arise. It would be interesting to get to know the numbers and the coal consumption of the kiln. Because of high cost of building the Mendheim gas kiln can scarcely be able to displace the simple kilns with direct firing in use, cheap to build and maintain.

In the analyses table of the silica bricks designated good, the composition of the brick, No. 8, designated the best approved, which possesses a proportionately high iron content but almost no lime, is remarkable. The analysis can not in this way influence the possible employment of *Silikanit* as binding material. The author asks if there must not here be a small error of analysis with regard to the quantity of lime generally used for the production of the bricks.

Dr. Lange correctly speaks almost exclusively of silica bricks. The designation "Dinas Bricks" has to-day really only a historical importance, and he who does not happen to know that these bricks were originally manufactured in England from the Dinas sandstone of the Vale of Neath in Wales, and came from there to Germany will be able to realize nothing from the term "Dinas Bricks." Since these bricks have been produced in Germany from the qualitatively much better "Findlingsquartzite," the old name has no claim, it even produces confusion. Some factories have retained the name

for their best quality bricks, and call their IIA quality (*e.g.*, bricks for fettling chambers) silica bricks, others do the reverse.

The author suggests that metallurgists and manufacturers of the bricks should use IA silica only for bricks of the best quality produced from "Findlings-quartzite" and lime bond, and IIA silica for the second quality with lime bond. The so-called "German Dinas" or "Clay Dinas Bricks" are produced from inferior quartz pebbles or from Devonian quartzites, and they should properly be called "quartz clay bricks." The author also observes that it would be of interest to ascertain whence the well-known yellow spots of the "Findlings-quartzite" are derived, what they consist of, and what influence they may exert on the quality of the rock. Also whether the basal cement of good tertiary quartzite, which appears opaque in the polarized light of the microscope, consists of amorphous silica, or whether as Dr. Wildschrey believes, it likewise possesses an extraordinarily small and therefore in a microscope of only medium power no longer discernible crystalline texture and therefore here only appears opaque.

MAGNESITE.—F. Bleichsteiner (*Oesterreichische Zeit. f. Berg-und Hüttenwesen* 40, 355, 1892). The use of basic materials for furnace purposes is not new. In earlier times it was not understood how to produce magnesite bricks of such high stability as they have attained very recently, so that now they are made from pure magnesite without any admixture. Clay admixtures have always been prejudical, bacause is is well known clay contains silica, and the alumina therefore according to the actual conditions can also react as an acid.

Refractoriness consists not merely in difficult fusibility of materials, but especially also in their capacity for resisting splitting or falling to pieces in the heat, shrinkage, fritting, swelling, and corrosion by melted material or fuel. It is therefore a fact that the difficult fusible (or in ordinary colloquial usage the infusible) refractory bricks are not always the best; it is just as well known how carefully the refractory material must be selected if the object is to be attained. It now seems easy to make clear theoretically whether or not the brick will answer the demands made on it, whilst in practice difficulties result in this case. Those materials are most refractory which contain only one base (limestone, magnesite), or which consist of silica (sandstone with quartz as bonding material), for as is well known the highest temperatures of all are required in order to melt either lime or quartz.

But lime, magnesite, quartz, have each in itself the evil property of breaking to pieces, of splitting, in the heat, a property which appears the more fully developed the purer the materials are, so that in practice no use can be made of them. The various clays, graphite, therefore play a very important rôle with refractory materials. It thus becomes compulsory to bring into use compounds in which silica is combined with an earth, as alumina (clay), magnesia (serpentine, steatite). But no alkalies, no iron oxide or the like must be present, and only one base should appear, because several bases only serve as fluxes and lower the refractoriness.

Mixtures of quartz with clay form the bulk of refractory materials. But bricks which occur in practice under the name of chamotte bricks should always be tried in order to know whether they answer for a certain purpose.

Quartz bricks consist of a mixture of pure quartz with clay; in case stability is not required they can be made very rich in quartz, whereby as a rule the refractoriness is raised. But if stability, resistance forms a chief rôle, the so-called chamotte bricks must be selected, which prove the more refractory the purer the clay, that is, the richer these bricks are in one base and the poorer they are in other bases acting as fluxes. But in practice this is very difficult to carry out, so highly refractory bricks or crucibles are very expensive.

That material would have the highest degree of excellence which, when thrown white hot into cold water, would neither split nor fall to pieces. Usually one can be quite satisfied if a white hot refractory brick will not become cracked in cooling in the air, because most clays possess the property of proving very durable in uniform heat, whilst they, as unfortunately occurs

besides with the blast furnace process in almost all metallurgical processes, are of little or no use when high temperatures alternate with rapid coolings.

For metallurgical purposes therefore the manner of using and the corrosion conditions must be taken into consideration; thus, for example, as much as possible basic furnace materials should be used for basic preparations and acid materials for acid preparations. Experience has shown, for example, that with rich coals different chamotte bricks are needed than with poor coals.

Among acid materials Dinas bricks have long played the chief part, but here a false view prevails that only absolutely pure quartz has to be used and no notice must be taken of stability, of refractoriness, and thus cases occur in which the very renowned Dinas brick factory supplies useless furnace bricks, without perceiving the cause of this failure.

Natural magnesite is crystalline, granular, compact (sometimes also passing into scaly), transparent and shining like mother-of-pearl, or dense, white and of conchoidal fracture. The white dense magnesite free from iron contains up to 99·22 per cent. magnesium carbonate, and as a rule forms fillings of clefts, fragments, cores, and lenticular aggregations; on the other hand, the crystalline granular magnesite, which usually contains the more iron the purer it is from lime, occurs in masses and beds of moderate thickness. The white, dense magnesite, which in serpentine particularly forms the fillings of cavities, was separated from a solution, which can either have brought its magnesium carbonate from a depth or taken it from the serpentine. The apparently stratified occurrence can be conceived as original deposits. On the other hand they are regarded as metamorphic formations, for example, as arising from dolomitic limes, from which by water rich in carbonic acid the whole of the lime portion was gradually carried off (dolomitisation). Both these explanations are open to serious objections.

Magnesite poor in iron gives a superior, very hard cement. Recently various branches of industry have been based on this property.

When magnesite is heated it becomes caustic at about 440° C. In this condition it combines with water, but remains soft; at dark red heat, however, cementation power begins, and if mixed with water it becomes very hard after some time. As soon as magnesite is ferruginous it loses the cementation power completely, and falls to powder in water. When magnesite is intermixed with calcium carbonate, and this mixture is burned, the properties of the burnt lime become prominent according to the degree of heat used; the rapid change of the burned lime in the air acts very disadvantageously. Whilst ferruginous magnesite sinters or frits in consequence of the influence of the iron, lime free from iron remains dead burned and after a short time can be removed in the form of powder from the sintered magnesite. This difference can readily be perceived by making bricks of the burned materials.

In default of magnesite, dolomite has been used as substitute in the iron industry, and this seems in many ironworks to be still always the case, on account of the low price. Numerous other auxiliary means are used, partly protected by patents, partly as secrets, in order ostensibly to produce useful basic material or to improve this, because it is not yet sufficiently known what favourable influence the pure sintered magnesite takes on the basic process. In order to explain this the formation of sintered magnesite may be somewhat exhaustively discussed. With regard to refractoriness dead burned lime as well as dead burned magnesia are the absolutely best materials, if these substances would form fast binding masses; but this is by no means the case. It is impossible to make a compact, firm brick, durable against wear and tear, etc., of pure lime or pure magnesia, just as it is impossible to produce a firm, impenetrable, even ground mass from the dead burned materials. The bottom rises or it is like loose sand without bond. Attempts are made to aid it with tar, pitch, etc., by which a weak bond would be possible, but a fritting, shrinking, splitting, makes its appearance, the power of resistance is small; in consequence of this a frequent renewal becomes necessary and moreover one has also to contend with the material itself, which mixes with the slag and even partly slags. Where dolomite is used, it is aided by burning twice, and the brick made from sharply burned, pulverized dolomite, again

exposed to the highest temperatures (sharply burned) and again pulverized (ground), in order thus prepared to come into employment. But magnesite which is somewhat ferruginous sinters at a sufficiently high temperature, that is, it frits very strongly if it is completely dead burned and is exposed to a still higher temperature, and has then even without addition of binding material a high binding quality, if it be firmly compressed. It loses this quality altogether, however, if the sintered magnesite is calcareous. On the other hand magnesite agrees very well with the clay as binding material if magnesite not completely sintered can be used.

It is believed that an iron content of 2 to 3 per cent. is most desirable. But a magnesite with only so little iron needs for sintering excessive temperatures. If it does not sinter it is merely dead burned, and is then absolutely bad; wherefore also those works which work with real sintered magnesite will never be able to decide to use only dead burned magnesite. This is quite comprehensible, because dead burned magnesite which contains even only traces of iron, clay, or quartz, first sinters at still higher temperatures, thus changes its volume, whilst sintered magnesite retains its condition, or at most could become soft if it were too rich in iron.

From the foreging it follows that all the kinds of magnesite occurring in nature can not be used for metallurgical purposes, especially for the basic process. Magnesite must, as already stated, above all be free from lime, and obviously may contain no impurities through quartz, clay, or any alkalies at all; on the other hand it should contain some iron oxide, and the author believes 3—4 per cent. would not be injurious, because through that only a complete sintering results and the magnesite remains in pieces, and then mixed with the finest magnesite powder and compressed, it unites (according to the author's conviction) without addition of tar to an absolutely compact, firm, and uniformly solid whole (*e.g.*, the bottom of a Martin furnace).

But the brick material itself will behave still better, because the bricks produced from this material are pure and sharp-edged, and have level smooth surfaces.

Very pure magnesite has talcose veins, which burn quite white and give the sintered magnesite an ugly appearance, yet are entirely harmless; these white grains are sometimes mistaken for quartz grains. Perhaps these can sometimes also occur when the magnesite is not sintered; if this be the case, then (in the author's opinion) the quartz must form a slag which trickles down and with some care can easily be removed. Every compact or crystalline magnesite appearing stratified contains some lime; yet it is at once recognised, particularly when sintered magnesite is produced, and since it easily becomes dust it can be completely removed. But it is quite wrong to use caustic burned magnesite for the basic process, or caustic magnesite dust for brick manufacture, as is usual in France and Germany. Pure magnesite has certainly ten times the durability of dolomite.

Moisture and air injure the sintered magnesite, therefore it must be preserved from these influences and the magnesite made red hot before use. On delivery of the magnesite it should be above all thrown through a screen, to separate the fine grains, as well as dust from the coarser. If the magnesite be calcined twice, it should again be thrown through a screen and the fine portion separated; this dust is certain to be more calcareous and should therefore only be employed for smaller repairs. The pure sintered magnesite, which in the way mentioned becomes free from dust, should then be pulverized to very fine powder, which is necessary in mixture with grains and pieces if a dense useful bottom is to be stamped. It is decidedly wrong to wish to dispense with the dust; it is just as little recommended to buy magnesite in dust form.

Magnesite is burned in flame furnaces, in Mendheim kilns, in refractory brick kilns and in shaft kilns. Magnesite burned thoroughly to sinter is obtained only from shaft kilns, and even this only when they have a suitable size and height and the firing arrangements are such that high temperatures are made possible. Thus, in order to make certain, better coal must be used for firing. Only two firms are known by the author to produce sintered magnesite, Carl

Späeter and the Styrian Rad-und Hütten-Gewerkschaft Hohenwang, and it is his conviction that the latter firm can produce sintered magnesite regular and most uniform, because this company has higher and larger kilns for burning than the firm of Carl Späeter. For sintering the magnesite time must be allowed (because the temperature must be the highest possible); the shaft kiln must therefore also have a certain height. But a greater height also requires a wider kiln (greater diameter of the shaft) in order to attain a uniform descent of the magnesite and in order to avoid the otherwise inevitable carrying forward of the freshly charged magnesite. Hence this continuous working is also extremely regular and with proper attention interruptions or variable action of the kiln never occurs.

In Witkowitz a Siemens gas furnace has been used for burning magnesite with excellent results, which qualitatively equal the Hohenwang yet quantitatively are inferior.

The firm Carl Späeter patented a shaft kiln for burning magnesite; though still earlier the Hohenwang Company made use of an old blast-furnace for this purpose. The author considers the patent to be only an imperfect imitation of the older contrivance.

As is well known, lining is often preferred to the very difficult beating out of basic furnaces and retorts, so the manufacture of magnesite bricks is very soon attempted. According to the author the full merit of having first produced magnesite bricks from pure sintered magnesite of the best possible quality is due to the Chamottefabrik in Witkowitz.

MAGNESITE.—Leo (*Oesterreichische Zeit. f. Berg. und Hüttenwesen*, 40, 486, 1892). A critical survey of F. Bleichsteiner's article. He takes exception especially to the statement in which the firm of Carl Später is compared unfavourably with the Hohenwang Company as regards the production of sintered magnesite, and claims that the former have higher and larger kilns, producing a no less regular and uniform product. He contends that the Späeter kilns are already so high that any further increase in the height of the kiln shaft would be quite without object or result, and that in their kilns nothing is known of a carrying forward of the freshly charged magnesite. The temperature of the hottest zone of a Späeter kiln is so high that the best Styrian Dinas bricks have in it only a severely limited duration so that in all rebuilding and new building of them only magnesia bricks are used.

The contents of the shaft sinters together so firmly in this zone that difficult work often lasting for hours must enforce its descent. Under these conditions the carrying forward of unfinished layers is impossible. It is inadmissible to increase the diameter of the shaft in the sintering zone beyond a firmly fixed limit, which is never exceeded in the Späeter kilns, for the developing change of state of the magnesite caused by the burning and sintering permits a fire influence on the contents of the shaft only as far as the well-defined central pit. Every outward stretch over that leaves a more or less cylindrical kernel kept back in the burning, and would not only call in question the superiority claimed by Bleichsteiner for wide kilns in providing only uniformly sintered products, but regularly nullify it.

Bleichsteiner's assumption that Späeter's kiln patented in 1886 was an imperfect imitation of the older Hohenwang contrivance is absolutely erroneous. The difference in time between the taking up of burning work on the part of Hohenwang and the patenting of that kiln is so small that it would not have sufficed for fulfilling the formalities which precede the bestowal of every patent. The Späeter kiln project was already worked out and settled earlier than Hohenwang had even only begun with the adapting of the blast furnace. For the rest the two kiln systems differ considerably from one another, and Bleichsteiner must have known that at that time the arrangements of the Hohenwang kiln were different from what they have been subsequently. On the contrary the second Hohenwang kiln built three years later appears to be an imperfect imitation of the 1886 patent shaft kiln of Späeter.

The secret of manufacturing bricks from only sintered magnesite is by no means the property of isolated enterprises, and neither in France nor in

Germany is it usual to employ caustic magnesia powder; that secret was brought into use at a much earlier time than has been supposed.

MAGNESITE.—F. Bleichsteiner (*Oesterreichische Zeit. f. Berg. und Hüttenwesen*, 40, 486, 1892). A vigorous rejoinder to Leo's criticism. The author controverts some of his critic's statements, and strongly reaffirms his own. Referring to the hottest zone (mentioned by Leo, but without any indication of its exact position in the kiln), he states that in a correctly constructed arrangement it lies at 0·5 metre to at most 2 metres above the place of influx of the gases, and from this last-named point upwards the kiln is to be kept markedly conical just like a blast-furnace above the bosh. The hot blast enters the kiln in the horizon of the gas-influx, which is 3 to 4 metres above the drawing-off opening, in order that the sintered magnesite may have space and time to cool, and can be collected together below. The pressure of the hot blast must obviously be increased with the height of the kiln, and is scarcely perceptible with low kilns. The temperature in this zone is thus the highest, and sinters the magnesite a little way above the influx of the combustion products. But since about 200 kg. raw magnesite is used for 100 kg. sintered magnesite, the sintering is associated with a very considerable diminution of volume; accordingly the gases, on account of the conical shape of the kiln, can easily be regularly distributed, because the sintered magnesite with regular working rapidly and continuously sinks below the influx of the gases. According to the quick action of the kiln the sintered magnesite is drawn, often hourly, but at least every two hours, and always remains quite uniform below. If it should be noticed that the entrance into the kiln does not become clear, that is an infallible sign that too little sintered magnesite has been removed, and 2 or 3 draws should be made, one after another, until the entrance again fully suits.

A greater height stipulates also a larger diameter, and since a larger kiln needs more gas, the firing arrangements should be such that cleaning, etc., happens only very seldom.

ON THE RESULTS OF THE USE OF CLAY RETORTS FOR GAS MAKING.—Jabez Church (*Proc. Inst. Civil Engineers*, 16, 309, 1857). The use of clay instead of iron for retorts is, perhaps, nearly the most important improvement in apparatus for manufacturing coal-gas. In 1826—27, Broadmeadows' patent was brought into operation by the late David Gordon, the introducer and patentee of compressed gas, and a paper on the subject is in the archives of the Institution. This compressed gas was obtained from coal-gas, made at Manchester by Alexander Gordon, with retorts constructed of bricks, Welsh lumps, and Stourbridge clay. Mr. A. Gordon states that the defect of the system was that, having to work with a very slight oscillation of the barometer or water-gauge, by Broadmeadows' apparatus, they sometimes blew gas through the joints of the brick retorts or ovens; at other times the ovens inhaled air owing to the exhausting apparatus being worked too rapidly, and this made it necessary to lay aside Broadmeadows' plan.

Mr. Grafton in 1820 apparently first adopted fireclay instead of metal for retorts, which were at first square in cross section, but soon afterwards it was changed to a D, or oven shape, which has since been adhered to both at home and abroad. In Scotland, clay retorts were adopted at a very early period, and they are now in general use there. Several quotations are given from S. Clegg's Treatise on Coal-Gas, concerning the power of clay retorts to retain their heat, etc.

According to the author's experience, in different towns, "the comparative quantities of gas made by iron and clay retorts, of the D form, and equal in size, that is, 15 inches by 13 inches on the cross section and 7 feet 6 inches in length, are as follows:—The duration of the iron retorts for 365 days, working off 1½ cwts. of coal for each charge, was equal to the carbonization of 2,190 cwt. of coal, which at 9,000 cubic feet of gas per ton, gives a total quantity of 985,500 cubic feet of gas per retort: whilst the clay retorts worked 912 days, carbonizing 5,472 cwt. of coal, which at 9,000 cubic feet of gas per ton, gives 2,462,400 cubic feet of gas per retort. The clay retorts are

capable of yielding a greater quantity of gas, from the same quantity of coal, than the iron retorts, but the specific gravity of the gas so made is less, and its illuminating power is diminished, in consequence of the increased temperature of the clay retorts above that of the iron retorts. Such an increase of temperature upon an almost exhausted iron retort would cause the metal to melt, whilst the clay retort would be unaffected by the degree of heat when the great body of gas yielded by the charge has passed off. The want of illuminating power in the last portion of gas, it is well known, is owing to the gas being decomposed by the higher temperature of the retort, when part of its carbon becomes deposited; but it is to be remembered that when the same quantity of gas is produced from equal quantities of coal, the gas in each case will possess the same illuminating power, whether carbonized in iron or in clay retorts."

Of the three forms of clay retorts usually employed—the circular or round, the D or oven shape, and the elliptical—the D shape is to be preferred, because this form of retort admits of a stratum of coal being distributed of an equal thickness throughout; but the form of retort must in some cases be regulated by circumstances, and it is not unusual to have these three forms of retort placed in the same bed. The cost of setting the clay retorts is sometimes as much as 20 per cent. less than for iron retorts, the former not requiring any tiles or shielding like the latter.

In small works the clay retorts are used without an exhauster. When that machine is not used, it is necessary to work at as low a pressure as possible upon the retort; but it is found in practice that they may be profitably worked at a water-gauge pressure of 7 inches. Should the pressure be increased beyond this, leakage takes place through the pores of the retorts, which leakage will always be in proportion to the pressure. Such leakage continues for a considerable period, or until the pores become filled by a deposition of carbon throughout the entire mass of the retorts, as seen in a broken retort exhibited.

The most practical method of working clay retorts in large works is with the addition of an exhauster, which serves to reduce the pressure on the retort by drawing off the gas. The further advantage of an exhauster is that the quantity of gas is increased about 200 cubic feet per ton of coal, this extra quantity being otherwise forced through the fissures and pores of the retort as the pressure increases. The same advantages would apply to small works, but the gas saved would not compensate for the expense of an exhausting apparatus and steam machinery to work it.

It is well known that the deposition of carbon is more abundant in clay than in iron retorts, owing probably to the greater temperature which the former acquire. Yet, as far as working is concerned, one retort may apparently be subject to the same conditions as another, but one may be more encrusted with carbon than the other; this may be attributed to the surface of the one which deposits the carbon being rougher than the other. "An experiment was made with twenty D-shaped retorts, set in four beds of five each. They were all worked at the same temperature, charged with the same quantity of Newcastle coal, placed on the same range, and were subject in every particular to the same conditions. During these experiments the resistance offered to the gas, in its passage through the purifiers and by the weight of the gasometers or gasholders, was equal to a column of water of 7 inches, by the gauge attached to the ascending pipe near the mouthpiece. The result was that ten retorts, during the time referred to, had a large accumulation of carbon amounting in weight to nearly 1 per cent. on the quantity of coal used, whilst the other ten had only a very small accumulation of carbon. These retorts were made by the same manufacturer in the neighbourhood of Newcastle, but ten were made from one seam of clay, and the other ten from clay of a different quality. In the one case the interior of the retorts in which there was the lesser deposit was evidently much smoother than the interior of the retorts in which there was the greater deposit. Hence it is concluded that the deposition is partly regulated by the nature of the surface, and that it is necessary that the interior of the retorts should be more carefully finished,

so as to insure a smooth surface, for which purpose a proper quality of clay should be selected."

When clay retorts are worked with an exhauster they are not so liable to the deposition of carbon as when worked without an exhauster, and a smooth surface with an exhauster possesses the same advantages as a smooth surface without an exhauster. As the structure of the carbon deposited in the retorts is always laminated, most of the carbon appears to separate from the gas at the earlier period of working the charge of coal, so that every time the retorts are charged and worked a distinct layer of carbon is formed upon the previous layer, as was demonstrated by specimens exhibited. The periodical removal of this carbonaceous incrustation needs greater care with clay retorts than in the case of the less fragile iron retorts. It is necessary both with clay and with iron retorts to admit air, which has the effect of rendering the carbon capable of being detached by means of chisel-ended bars. When the retorts are long and have a lid at each end, the air can be at once admitted by removing the lids, but in short retorts having only one lid the usual plan is to partially remove the lid from the mouthpiece of the retort, and to let it remain in this state until the current of air which establishes itself through the retort renders the carbon capable of being easily detached. This process in some cases requires nine to thirty hours before the removal of the carbon can be effected. The author after various trials found the following to be the easiest and quickest method of accomplishing the object. "An ordinary lid, provided with a hole as near the lower part as practicable, and large enough to admit a fireclay pipe 3 inches in diameter, is luted on in the ordinary way. The blank flange at the top of the ascending pipe leading to the hydraulic main is then removed, and a temporary connection is made with this pipe to another iron pipe of similar diameter, the other end of which is made to terminate in the main flue of the retort stack leading to the chimney-shaft. The clay pipe being passed through the orifice in the lid is placed in such a direction that the end within the retort shall cause the current of air which is drawn through it to impinge upon the mass of carbon which it is intended to remove. The inclination of this pipe can be changed from time to time, so that the air may be made to play successively over the whole surface of the carbonaceous mass. A clay pipe is preferred to one of iron because the latter would be rapidly oxidized. The advantage of this method is that it requires only half the time for the removal of the carbon." The longer the retorts are subjected to the action of cold air within, the more they are liable to suffer from formation of cracks or fissures. Should any more practicable and advantageous method than that just described be known, it is desirable that it should be pointed out.

It has been found that where proper judgment and skill are exercised in the construction and working of clay retorts the quantity of coke required for heating them, in ordinary working, ranges from 25 to 30 per cent. of the quantity of coke made—assuming that Newcastle coal is used, and that a chaldron of coke is afforded by each ton of coal. Iron retorts may be heated with precisely the same results. In the case of short retorts, the clay retorts possess no economical advantages over iron retorts of the same size, as far as the fuel for carbonization is concerned. But with long clay retorts, say 20 feet, a saving of fuel would be effected, as the same fuel required for heating two beds of iron retorts 7 feet 6 inches long, placed end to end, would heat the clay retorts 20 feet long, thus giving 5 feet of additional length for each retort; that is to say, the brickwork partition required for the iron retorts being no longer necessary enables the space it occupied to be added to each clay retort, and thus "the quantity of fuel for carbonization is reduced to a percentage varying from 19 to 24." It is to be understood that the usual time of working both the long and short retorts is six hours for each charge of Newcastle coal.

"It appears then that the principal advantages arising from the use of clay retorts are:—That there is a saving of about 20 per cent. in the setting, compared with the expense of setting iron retorts, and that the average durability of clay retorts in work is two years and a half, whilst iron retorts

of the best quality only last one year. It may be added that the first cost of clay retorts does not amount to more than half that of iron retorts."

Mr. Henry Gore concurred in the general principles enunciated in the paper, and related some personal experiences. In Leeds, the coal used for the manufacture of gas was a kind of bastard cannel, found near Wakefield and Dewsbury, mixed with about one-third of the ordinary soft coal of the district. With the ordinary iron retorts the maximum amount of gas obtained was from 7,600 to 8,000 cubic feet per ton, about 37 per cent. of the coke being consumed for fuel, and the gas produced having an illuminating power of 17 sperm candles. Since the introduction of clay retorts the average make of gas was from 9,100 to 9,200 cubic feet per ton; and he believed that result —considering the specific gravity of the gas delivered to the public—was satisfactory. But the fuel used in producing that quantity of gas amounted to about 60 per cent. of the coke that was made. London engineers would probably characterize that as a wasteful and negligent process of manufacture, but the fuel they had to deal with in Leeds was totally different in character from that used in gas-works in London and the south. The coke itself was light and friable, and contained a large proportion of earthy matter, and to keep up the heat in clay retorts necessary for producing the amount of gas mentioned they were obliged to have recourse to hard firing, and a much greater draught was essential than was necessary in London and its vicinity. At Doncaster, which showed a striking contrast, the coal used in the gas-works was chiefly from the Darley Main, mixed with a portion of the Silkstone seam, from the Thorncliff collieries of Messrs. Newton & Chambers. This mixture, at a fair working heat and with six-hour charges, produced about 9,400 cubic feet of gas per ton, of the average specific gravity of 420, and having an illuminating power equal to 14½ candles, whilst they could sell from the yard nearly 75 per cent. of the coke produced. Thus before the economy of clay retorts could be satisfactorily settled, all the conditions affecting the question, both as to the material to be employed and the form of retort to be used, must be taken into consideration

Another important point was the mode of setting the retorts. The general plan in London and neighbourhood was to set them in beds of 5 or 7, and in some cases beds of 11 retorts, with one, or two, fires. No doubt that arrangement was applicable to the nature of the fuel obtained in the locality, but in Yorkshire it would entirely fail. At Doncaster he found he could work the retorts, set in beds of 5, with one fire, with a satisfactory result as to the heating power of the furnace, but the wear and tear of the furnace itself was excessive. The same class of bricks that in London would last from 12 to 15 months would be destroyed in 7 or 8 months at Doncaster. This necessitated an arrangement of setting that would offer facilities for renewing the furnace without destroying the retorts. By a mode of setting he had adopted, the entire furnace could be reconstructed at a cost of about 13 shillings per set of 5 retorts. At Lancaster this arrangement was a failure, the beds of five retorts there requiring two fires, or double the furnace space; but the heat was so much increased that instead of 9,600 cubic feet of gas per ton the produce was nearly 11,000 cubic feet per ton. The fuel employed at Lancaster was Wigan cannel, mixed with a small portion of the black coal of Manchester. The average illuminating power of the gas was 21 sperm candles.

Mr. A. Wright said his experience tended to confirm the statement of the author of the paper, that the amount of gas produced was about the same from iron and clay retorts. Under particular circumstances more favourable results might be obtained with clay retorts, but he did not think it could be relied on in general working. An iron retort being thinner, and having therefore less latent heat than a clay retort, cooled down to a greater degree when putting in the charge of coal, and it was some time before it got heated up again to the best state to eliminate gas. Clay retorts being thicker and having a greater amount of latent heat in reserve were not so much reduced in heat when being charged, and were better fitted to eliminate the gas than iron retorts. At the same time clay was to a certain extent porous, whilst

iron was comparatively impermeable to gas, so that although a large quantity of gas was eliminated in the former case he did not think any more passed into the gasholder.

He had ascertained that leakage of gas from heated clay retorts under pressure was in the direct ratio of the pressure, which was difficult to account for, the general law of the passage of gas through orifices being that the leakage was as the square root of the pressure. He agreed with the author that up to 7 inches pressure clay retorts might be worked economically, but at 12 inches pressure the excess of quantity eliminated was more than compensated for by the permeation through the pores of the retort. He had found that where the somewhat costly process of exhaustion could not be used iron retorts had considerably the advantage over clay retorts, and he believed it might be taken as a rule that where fewer than 10 retorts were employed the ordinary iron retort 7 feet 6 inches long, would be more economical than clay retorts. This would, however, be affected to some extent by the price of coal and coke in the district. If coal were cheap, and coke sold at a good price, the latter would compensate for the leakage in clay retorts.

At the Western Gas Co.'s works he had substituted clay retorts for iron, and now had not one iron retort at work, but he did not work them at the high heat which was regarded as most economical, because that would result in the formation of a greatly increased amount of carbon disulphide, which cannot be removed from the gas by any chemical agent hitherto discovered without also removing the entire illuminating matter of the gas. Carbonic acid and sulphuretted hydrogen were readily removed by hydrate of lime, oxide of iron, etc. The quantity of carbon disulphide might be represented as varying from 1 to 5, the sulphuretted hydrogen being 40; that is, gas could be made so bad from the presence of carbon disulphide alone as to be equal to from $^1/_{40}$ to $^1/_8$ of the ordinary impurity of gas before purification. Yet by the usual tests it would not be detected.

He agreed that the first cost of erection of clay retorts was only about half that of iron, and that the clay retorts would last for $2\frac{1}{2}$ years, whereas iron would not last more than 12 months; but the author omitted to state that when the retorts were made through and through (both ends open) there was less carbon deposited and less fuel used. He considered that the saving in the manufacture of gas from the use of clay retorts was threepence per 1,000 feet, but subject to the presence of more carbon disulphide from working at higher temperatures.

Mr. F. J. Evans observed that clay retorts would not produce the same amount of gas per ton as iron retorts, if both were at the same heat, when first charged. The best way of testing this was to draw the charge of coal from each kind of retort after it had been at work an hour and a half, and then to look at the state of the heat. It would be found that the clay retort was cooler than the other. The impression with regard to clay retorts was that as they could be worked at a higher heat than iron a larger quantity of gas was produced. As to the carbon disulphide, Mr. Lewis Thompson's recommendation was to leave a small quantity of ammonia in the gas, when the sulphurous acid formed by the combustion of the carbon disulphide combined with the ammonia, ultimately forming sulphate of ammonia, which was innocuous. He had found clay retorts to last in good order for 3 or 4 years, with every prospect of their continuing longer. He had found experimentally that leakage of gas through mains was invariably in the direct ratio of the pressure, such leakage being solely due to the joints of the pipes and not taking place through the metal. Some years ago he had closed a cast-iron pipe at each end, and allowed a pressure equal to 4 inches of water to remain on it for 6 months, at the end of which time no perceptible amount of gas had passed through, although the apparatus used was very delicate.

Mr. Gore described some experiments on leakage, made in Leeds, which had given similar results.

Mr. C. W. Siemens said he thought Prof. Graham's experiments upon the transpiration of gases bore somewhat upon the question of leakage. Those experiments went to show that when gases flowed through narrow tubes they

did not transpire or issue in proportion to the law of gravitation but according to some totally different law, not yet clearly laid down. A possible explanation was that the gas, in issuing through very small capillary spaces, was so much checked in its progress that its inertia was destroyed at every step, and it was only the excessive friction which retarded it virtually. But if it was merely the friction that had to be overcome, the leakage would be in proportion to the pressure applied. This argument would apply in a greater degree with regard to gas than air, because the specific gravity of coal-gas was only 0·5 at its ordinary temperature, and less than half that when heated to 800° in the gas-retort. The inertia of the gas was thus exceedingly small, but being highly elastic, the friction was considerable. With reference to the greater quantity of gas produced from clay retorts than from iron retorts, he suggested the possibility of the exhauster having been worked to a greater extent in such cases, so that leakage was into the retort from the exterior.

Mr. W. Strode said that at Chipping Norton gas-works he had used coals from Staveley, near Chesterfield. With iron retorts be produced an average of 9,000 cubic feet per ton. Two or three years ago he adopted small D-shaped clay retorts, made of Stourbridge clay, the production of gas being about the same both in quantity and quality as before. In one respect clay retorts had an advantage in small works, that is, where tar was a drug, for it could be applied to the fire, and an excessive heat be obtained by it without injury to the clay, though it would be very detrimental to an iron retort. He had therefore adopted the plan at Chipping Norton of using clay retorts and burning the tar in the winter, and iron retorts burning coke in the summer. At Banbury Mr. T. A. Hedley used long clay retorts, with lids on each end, put together in 2 or 3 rings, and set in beds of 4 or 5 over one fire. There, from the same Staveley coal, an average of only a little more than 7,000 cubic feet of gas per ton was obtained.

Mr. E. Goddard said he had had some clay retorts in operation for 3 years, and they appeared now to be in as good condition as they were a year ago. He had not found the produce of gas from the clay retorts so much greater than from iron retorts as had been stated. The formation of carbon took place more rapidly when the retorts were rough upon the inside than when they were smooth. He had sometimes entirely cleared the retorts of the carbonaceous deposit by the introduction of a fine jet of water.

Mr. Fraser remarked that in Scotland fireclay retorts had been used for 30 years, and for nearly 20 years exclusively in every works of any size except one. In every case (with this one exception) where one, or at most two, clay retorts could be continuously worked, the Scotch managers never thought of using iron retorts. He had visited nearly all the gas-works in Scotland, and had supplied clay retorts regularly to upwards of 100 works, and he could confirm the statement made in the paper. There was no doubt that smoothness of the internal surface of retorts reduced the amount of carbonaceous formation, and such retorts were most in demand. This was first brought to his notice by the manager of the Montrose gas-works, who subsequently wrote him that Inverkeithing retorts were not so liable to the carbonaceous deposit as other retorts that had been tried. A simple plan for removing the deposit of carbon was followed at Stirling and some other Scotch works. This was to throw a little common salt into the retort, which it was stated, with the admission of air, dissipated the carbon very quickly and effectually. (The salt was employed solely to dissipate the carbon after it was formed, and not to give a glaze to the retort, as was afterwards suggested by Mr. C. May.) The amount of coke required as fuel for carbonizing depended on the quality of the coal. In Scotland, where they principally used fine cannel coal, scarcely an ounce of coke was left to heat the retorts. Torbane-hill and Kirkness best cannel coal left none whatever, all the carbon being carried off with the hydrogen. It was thought very good working, if sufficient 'char' was left, even with second class cannel coal, to keep the retorts going. The cost of iron retorts to the Dumfermline Gas Co., including protections and setting, was £154 per annum, as compared with £20 for clay retorts. Other returns showed a difference as between £120 and £160 per annum for iron, and £23

for clay retorts. He calculated the cost of clay retorts as only one-eighth that of iron, including the setting, and their durability was much greater.

Mr. Josiah F. Fairbank stated, through the Secretary, that he had had some iron retorts in constant work for $2\frac{1}{2}$ years, and the quantity of gas produced by them was quite equal to what had been stated as having been eliminated from clay retorts. He would, at some future time, prepare a paper on the subject for reading at the Institution.

Mr. T. Hawksley pointed out that although clay retorts, when well set and carefully managed, might unquestionably endure twice or thrice as long as iron retorts, and the materials of these retorts and their settings were cheaper than those of iron retorts, yet there were several important items of charge which, under certain circumstances, would turn the balance in favour of iron retorts. Assuming the cost of an iron retort, mounted for use, to be £10, and of a clay retort, also mounted for use, to be £7, the durability of the latter to be $2\frac{1}{2}$ times that of the former, the quantities of gas made in each to be respectively 900,000 cubic feet and 2,250,000 cubic feet prior to final destruction, the selling price of coke to be 15s. per ton, the consumption by iron retorts $^3/_{10}$ of the quantity made, and by clay retorts $^4/_{10}$ of the quantity made, and that one ton of coal carbonized would produce $\frac{2}{3}$ ton of coke, then the amount for equal productions of gas would stand thus:—

	Iron Retorts	Clay Retorts
	£ s. d.	£ s. d.
1. Materials and setting	£10 × $2\frac{1}{2}$ = 25 0 0	7 0 0
2. Extra repairs of furnaces, etc. ...	... ...	1 10 0
3. Expenses of exhauster, etc. ...	... ...	1 5 0
4. Blowing-out apparatus, etc. ...	... ...	0 5 0
5. Coke used in furnace	... 37 10 0	50 0 0
Total	... 62 10 0	60 0 0

This shows that with circumstances as stated, iron retorts and clay retorts would be of nearly equal value. If coke were dearer, iron retorts would be preferable, and if it were cheaper clay retorts should be preferred. But coal varies much in quality, and so does the quantity and quality of the coke produced, so the gas engineer must be governed by the particular circumstances with which he has to deal. Clay retorts are well adapted for generating gas from the Scotch cannel coal, which produced coke of no appreciable value, but it may be doubted whether they are, in useful effect, equal to iron retorts for the distillation of coals yielding a large quantity of liquid matter, as, for instance, with coals which yield 350 lb. per ton of ammonical liquor instead of the usual quantity of 100 lb. Nor are they to be commended for small works, using coal producing valuable coke, for in such works an exhauster could not be applied; neither is the management of the retorts so careful as in larger establishments, conducted under intelligent and experienced supervision. Clay being a porous material allows the gas to transpire through its capillary passages, and hence it is better to work under a low pressure instead of at a pressure of 7 inches as had been suggested. Clay retorts would not evolve more gas than iron retorts, nor indeed so much, if they were not by the expenditure of a much larger quantity of fuel sometimes worked at a much higher temperature than would be prudent with iron retorts. The additional quantity was obtained in many such cases not only at the expense of the illuminating power, but also at the expense of purity. As regards leakage there was no real anomaly, for the law of the transmission of fluids through tubes was well known to be represented by the formula $P \propto av^2+bv$, in which P represents the pressure, v the velocity, and a and b two experimental coefficients. Now when the motion is minutely slow, as it always is

through capillary tubes and porous substances, v^2 becomes indefinitely small in respect of v, and consequently $v \sim P$, or, in other words, the quantity lost is as the pressure placed upon the retort. The same law obtains in the leakage of gas from mains; hence it is discoverable by mere observation whether the loss is from a broken pipe or from capillary apertures, because in the former case, the loss under a given head P would be $\sqrt{P}$, while in the latter case it would be as P simply.

He believed that the greater deposition of carbon in clay retorts arose largely from the decomposition of the gas transpiring through the substance of the retort. The gas parted with its carbon while entering the highly-heated pores, and the carbon was consequently left on the inner surface of the retort.

Mr. Church observed, in reference to the statement that an increase of 1,600 cubic feet of gas per ton of coal was made by the introduction of clay retorts instead of iron retorts, that either the iron retorts were not heated to the proper temperature, or the gas made from the clay retorts was of inferior specific gravity and consequently of low illuminating power. The quantities of carbon disulphide generated were as nearly as possible the same both in clay and in iron retorts when worked at equal temperatures. By leaving in the gas a small quantity of ammonia the effect of the carbon disulphide was neutralized. When clay retorts were worked under proper conditions they produced gas of illuminating power and purity equal to that from iron retorts. The calculation made to show that the merits of iron retorts had not been fairly set forth in the paper differed widely from the results of his practice. The fact of clay retorts having become almost universally used by gas companies was a strong argument in support of his conclusions. He had stated that there was a argument in support of his conclusions. He had stated that there was a great advantage in working with an exhauster, at a minimum of pressure, and that without an exhauster the maximum of pressure should be 7 inches of water. When the pressure was increased, the leakage was increased in the same ratio; hence the necessity of working at as low a pressure as possible. The reason why he had given 7 inches was because with the ordinary apparatus, without an exhauster, the resistance was equal to the pressure, and could not practically be reduced below it. Short clay retorts did not require a larger quantity of fuel for heating them than iron retorts, assuming coke made from Newcastle coal to be used. When long clay retorts were used a saving of at least 5 per cent. of fuel was effected as compared with iron retorts.

Mr. G. H. Ramsay remarked, through the secretary, that he had made clay retorts 35 years ago, and had some of them now. They were circular in section, 15 inches in diameter. Had they been used with an exhauster he did not doubt they would have proved quite equal to any now manufactured. Great skill and care was necessary in making retorts. When well set they would last 3 or 4 years, but he did not think it economical to work them too long. At the City Gas Works some of his retorts had entered upon their third year, and some had lasted even longer. An exhauster still appeared to be necessary for working clay retorts, and this might be expected to be the case as long as the gas companies bought low-priced retorts of indifferent quality, as many of them did. If, however, encouragement was given to the manufacturers of good retorts the companies would soon perceive the advantage, and in time the expense of exhausters might be avoided.

TESTING PHYSICAL QUALITIES OF MATERIALS.—W. and T. Avery, and H. W. Goulding (*Pat. J.*, No. 1,422, 1916). Pat. No. 24,517, Dec. 23rd, 1914. A testing machine in which the poise weight is moved automatically by a special weight, and the gearing is automatically braked as the steelyard falls.

TESTING PHYSICAL QUALITIES OF MATERIALS.—W. and T. Avery, A. W. Brown, and E. A. Allcut (*Pat. J.*, No. 1,482, 1917). Pat. No. 105,669, June 16th, 1916. An impact testing machine of the pendulum type. The construction enables the indicator which represents height of swing to be equally divided.

REFRACTORY SUBSTANCES.—O. Knöfler & Co. (*Pat. J.*, No. 1,429, 1916). Pat. No. 2,438, Feb. 16th, 1915. Fireproof vessels, etc., such as crucibles, are made from a watery paste containing very finely powdered oxides of titanium, beryllium, zirconium, thorium, or rare earths, or mixtures of such oxides, with a colloidal hydroxide of one or more of these metals and a little free acid. Solid sol or a colloidal solution may be employed. The proportions may be 1 part of solid sol and 100 parts of solid oxide, and the paste should contain about 0·1 per cent. of free acid. The cast or moulding is dried and rapidly calcined to about 2,100° C., for example, in the case of zirconium oxide.

REFRACTORY SUBSTANCES.—W. R. Just (*Pat. J.*, No. 1,433, 1916). Pat. No. 4,080, Mar. 15th, 1915. Equal proportions (but may be varied) of carborundum and zirconia are mixed, moulded, and burned. The product is used as a refractory material for muffles, crucibles, furnace linings, building materials, or for electrical resistances.

BRICKS FOR GAS PLANT AND COKE OVENS.—E. J. Davison and C. P. Tooley (*Pat. J.*, No. 1,425, 1916). Pat. No. 745, Jan. 18th, 1915. Relates to special bricks for constructing the chequer-work of regenerators for furnaces and of carburetting-chambers in gas plants. Reference is made to Specification 436/06.

REFRACTORY COMPOSITIONS.—J. B. Sidebottom (*Pat. J.*, No. 1,429, 1916). Pat. No. 2,578, Feb. 18th, 1915. A composition for lining crucibles consists of 112 parts of yellow sand and 8 parts of gas tar. The composition is placed in the crucible and baked for 5 hours at 200° F.

REFRACTORY BRICKS.—T. Twynam (*Pat. J.*, No. 1,466, 1917). Pat. No. 15,163, Oct. 27th, 1915. Refractory bricks are made with a single burning by mixing and grinding magnesite, dolomite, limestone, or lightly burned magnesite with not less than 20 per cent. and not more than 80 per cent. of chrome iron ore. A burning temperature of 1,600° C. is suitable, and, in moulding, a high pressure is avoided.

REFRACTORY SUBSTANCES.—T. Twynam (*Pat. J.*, No. 1,463, 1917). Pat. No. 102,386, Jan. 3rd, 1916. Refractory bricks and cement for furnace linings are made by mixing preferably 3—10 per cent. of slag wool with dolomite, magnesite or limestone without preliminary shrinking, and then firing at a high temperature. A less porous brick is obtained by an admixture of 20—30 per cent. of highly shrunk ground magnesite to the carbonate and slag wool mixture, or by grinding the burnt bricks, remoulding, and again firing.

REFRACTORY SUBSTANCES.—Mineral Products Co. and P. R. Hershman (*Pat. J.*, No. 1,472, 1917). Pat. No. 17,447, Dec. 13th, 1915. Material capable of forming a refractory carbide, such as aluminium dust, alumina, and calcined alunite, is mixed with insufficient carbon (such as finely ground coke) to convert the whole of the material into carbide, and the mass is heated slowly and gradually, without melting, to 1,500—2,200° C., until a refractory product suitable for furnace linings, bricks, flue linings, vessels for holding hydrofluoric acid, etc., is obtained. The mixture may be briquetted with tar or glue prior to heating. Porosity may be produced by adding straw or carbonates, and the heating is preferably conducted in an atmosphere which contains little free oxygen, for example, producer gas.

CARBORUNDUM ARTICLES.—G. A. Balz (*Pat. J.*, No. 1,473, 1917). Pat. No. 103,818, Dec. 19th, 1916. Carborundum articles, which are refractory and resist the action of chemicals, are made by mixing powdered or granulated carborundum, for example firesand, with calcium hydrate or other alkaline-earth hydrate and water, moulding or pressing, drying and burning at 1,400° C. or higher. It is preferable to frit or flux the mass. The percentage of carborundum in the finished product is preferably 98.

REFRACTORY MATERIALS FOR COKE OVENS, ETC.—M. Barrett and Leeds Fireclay Co. (*Pat. J.*, No. 1,475, 1917). Pat. No. 103,953, Aug. 18th, 1916. As a means of preventing disintegration, the surfaces of blocks of refractory material, made, for example, of 70 per cent. of Leeds fireclay, 10 per cent. of sandstone, and 20 per cent. of calcined fireclay, for building the walls of by-product coke ovens, gas-retorts, etc., which are to be in contact with the coal, etc., are polished immediately the blocks are made; the blocks are then air-dried and kilned, and, while still incandescent, at not less than 1,300° C., are treated with hot vapours of one or more alkaline chlorides for about 30 minutes. The parts not required to be treated may be coated with a wash of barium sulphate, or simply placed in close contact with each other.

REFRACTORY SUBSTANCES.—F. J. Tone (*Pat. J.*, No. 1,487, 1917). Pat. No. 106,393, Sep. 11th, 1916. In a refractory article consisting of a mixture of silicon carbide and a vitrifiable binder (such as kaolin or highly refractory fireclay), which is inert towards silicon carbide, a variety of sizes of grains of the carbide is employed so as to give an apparent density to the article, when pressed, of not less than 2·3. The binder vitrifies at a temperature of not less than 1,500° C. and is present to the extent of less than 10 per cent. of the mixture. Thus equal parts of 16, 24, 36, and 100 mesh (per lineal inch) grains may be used, and fine powder added if required. After pressing at about 3 tons per sq. inch into bricks, furnace linings, etc., it is fired to soften the binder (at not less than 1,500° C.).

TESTING HARDNESS OF MATERIALS.—G. Boyelle-Morin (*Pat. J.*, No. 1,497, 1917). No. 108, 460, April 24th, 1917. Apparatus for ascertaining the relative hardness more especially of metals by means of the impression producible by a ball of superior hardness.

POROUS, REFRACTORY, ACID-PROOF, AND HEAT-INSULATING MATERIALS.—M. Barrett (*Pat. J.*, No. 1,498, 1917). Pat. No. 108,619, Dec. 2nd, 1916. A porous refractory mineral product is made from a mixture of crystalline silica or vitrified siliceous material, such as sandstone quartz, chert, porcelain, and stoneware, with a relatively small proportion of felspar or felspathic material combined chemically and mechanically by heat at a temperature of at least 2,000° F. with or without dextrine, gum, or like adhesive, and preferably with the addition of a small proportion of tar and sodium or potassium silicate. The finely ground material is mixed with water and moulded under high pressure. An example of proportions is:—4 cwt. silica, 1 cwt. felspar, 7 lb. dextrine, 14 lb. tar. Various uses of the product are mentioned.

REDUCING PLASTICITY OF CLAYS.—Ger. Pat. 295,719, May 30th, 1915. Highly plastic clays contain fatty substances which can be removed by ordinary methods of fat extraction, leaving a dry friable material. The latter is good for mixing with other clays or as a substitute for grog, resembling Scotch fireclays.

GRINDING SURFACES OF GRINDING AND CUTTING WHEELS, ETC.—W. H. Jenkins (*Pat. J.*, No. 1,480, 1917). Pat. No. 105,296, July 14th, 1916. Grinding and abrading surface of grinding wheels is composed of 16 parts fine carborundum, 4 parts coarse carborundum, 4 parts of steel "crystals" or "grits" (angular fragments of a specially hard steel), all intimately mixed and bound together with 6 parts shellac or the like.

ABRASIVE WHEELS.—C. R. King, U.S. Pat. 1,208,330, Dec. 12th, 1916. A porous abrasive wheel is dipped in a cold solution of a synthetic resin. It is then heated to convert the resin into a hard tough bond.

ABRASIVE MATERIAL.—H. T. Kalmus, U.S. Pat. 1,226,892, May 22nd, 1917. The substances from which the material is to be made (*e.g.*, aluminous material) are fused in an electric furnace, and the fluid mass poured in a thin stream on to a moving surface so that the solidified material forms thin layers.

MATERIAL FOR ELECTRICAL INSULATION, ETC.—F. M. Locke, U.S. Pat. 1,226,088, May 15th, 1917. An insulator for high voltage current is produced by melting silicon and boron compounds with a fluorine compound, and moulding the homogeneous mass.

THE ADSORPTIVE POWERS OF CLAY, KAOLIN AND RED MARLS.—Prof. R. Rohland (*Deut. Top. Zieg. Zeits.*, 76—7, 333, 1915). H.E.W.

METHODS FOR PREVENTION OF SCUM IN TILES, ETC., WHERE BODY CONTAINS SULPHATE OF LIME.—(*Deut. Top. Zieg. Zeits.*, 46—7, 199, 1915. H.E.W.

SPECIFIC HEATS OF BUILDING AND INSULATING MATERIALS.—M. Kinoshita (*Zeits. angew. Chemie.*, 30, Ref. 65, 1917. Also *Gesundheits-Ing.*, 39, 497, 1916). The average specific heats between 0° and the stated temperatures (t° C.), as determined by means of an ice-calorimeter, and the volume-weights (in kilogs. per cub. m.) of the respective materials, are given in the following table:—

	t° C.	Kilogs. per cub. m.	Kilog. Calories	
			per kilog.	per cub. m.
Cork expanded, but not impregnated...	65	163	0·433	70·6
	57	163	0·433	70·6
	44	163	0·432	70 4
	64	163	0 446	72·7
	22	163	0·410	66·8
Cork greatly expanded	44	57	0·342	19.5
	47	57	0·325	18·5
	20	57	0 335	19·1
Natural cork	48	152	0·433	65 8
Natural cork	102	162	0·419	67·9
	48	162	0·421	68 2
	22	162	0·403	65·3
Cork bonded with pitch	49	190	0·361	68·6
Cork expanded and impregnated ...	47	206	0·312	64·1
Raw silk	35	564	0.318	179
Straw	36	284	0 211	59·9
	50	284	0 188	53·4
Kapok fibre	36	142	0·320	45·5
Kieselguhr	38	242	0·212	75·8
Marble	34	2682	0·194	518
	21	2682	0 184	494
Sand-lime bricks	16	2122	0·202	429
Fine concrete	16	2133	0·210	448
Rough concrete	16	2204	0·213	469
Bricks	49	1645	0·178	293
	27	1645	0·177	291
Slate	20	2816	0 181	510
Cast Asphalt	20	2102	0·224	471
	19	2102	0·223	469
Rammed Asphalt	21	1681	0 213	358

PROPERTIES OF BRICKS, ETC. PROPOSED STANDARDS.—H. Burchartz (*Mitt. Königl. Materialprüfungsamt*, 34, 79, 1916. A series of proposed standard values for each type of brick, which should be readily attainable under commercial conditions, has been arrived at by a careful classification and examination of the results of approved tests applied to

samples during the years 1907—1913 at the Materialprufüngsamt, as follows:—*Volume-weight* in grms. per c.c., for clinker bricks 1·85, for hard-burned ware 1·75, for building bricks (first quality) 1·60. *Specific gravity*: Clinker 2·6—2·7, hard-burned 2·6—2·7, building bricks (first quality) 2·6—2·75. Specific gravity decreases very slightly with harder burning, average values being 2·650, 2·660, and 2·680 for the three types respectively. Specific gravity will vary a little according to the material, but no building brick should have a lower specific gravity than 2·50. *Impermeability* is calculated from the apparent volume-weight (as above) and the specific gravity, by using the formula $1 - \frac{\text{Volume-weight}}{\text{Specific gravity}}$. *Absorption of water* varies considerably even among the same kind of bricks, and bears no direct relationship to the strength. It is only necessary to suggest standards for clinker and hard-burned bricks which are much used for conduits and should have a certain degree of water-tightness. An absorption of 5 per cent. by weight or 10 per cent. by volume is proposed for clinker, and 8 per cent. by weight or 16 per cent. by volume for hard-burned. *Crushing resistance.*—The standards already adopted by the German building trade association are certainly not too high. They prescribe a crushing resistance, in kilogs. per sq. cm., of 350 for clinkers, 250 for hard-burned, 150 for first quality building bricks, and not less than 100 for second quality building bricks to be used in interiors. The author suggests 180 as a reasonable standard for first quality building bricks. The ratios of crushing strengths when saturated with water and after repeated freezing to the crushing strength of the dry brick are important, and it is suggested that the average loss of strength in the saturated condition should not exceed 15 per cent., and that the loss after freezing should not exceed 25 per cent. Bricks should be free from lumps of lime, and finely divided lime should only be present in harmless amounts. Abrasion tests should be applied to clinkers so as to ensure that their resistance to wear shall be at least as good as that of other artificial paving materials.

III.—THE COMPOUNDING & PREPARATION OF CLAYS AND BODIES.

PLASTIC COMPOSITIONS.—F. E. Eaton (*Pat. J.*, No. 1,421, 1916). Pat. No. 24,266, Dec. 18th, 1914. A mixture of 86 to 98 per cent. of calcium carbonate (chalk), 1·98 to 12·5 per cent. of calcium phosphate (powdered bones), and 0·02 to 1·5 per cent. of silica (sand), together with a suitable binder, is used for forming dolls' heads, etc. Suitable binders are: (1) a mixture of 1 quart of glue solution, 1 teaspoonful of Venice turpentine, and 1 pint of a strong solution of alum, or (2) a mixture of a solution of casein, water-glass, and gum arabic.

MAGNETIC SEPARATORS.—O. C. Jones (*Pat. J.*, No. 1,491, 1917). Pat. No. 107,284, Aug. 5th, 1916. Relates to magnetic separators for treating semi-liquids such as paper pulp, potters' slip or oils, or granular or powdered material.

CARBON BRICKS AND CARBONACEOUS CERAMIC BODIES.—Dr. K. Albert and L. Berend, Ger. Pat. 294,661, Aug. 10th, 1913. Carbon, or a mixture of ceramic raw materials, is intimately mixed with an aqueous emulsion of an organic substance with an organic emulsifying agent, both of which yield finely divided carbon on carbonization, and the mixture is heated to carbonize the non-volatile constituents of the emulsion. As emulsifying agent, concentrated sulphite-cellulose waste lye is recommended, and as substances to be emulsified, tar, tar oils, or fatty oils. The raw mixture, before carbonizing, may be used for lining furnaces, etc.

FURNACE-LINING MATERIAL.—C. J. Barr, U.S. Pat., 1,206,771, Nov. 28th, 1916. Grains of non-fluxing refractory material, such as dolomite, are roasted in a rotary kiln, and a less refractory material, such as pulverised slag, is blown into the discharge end of the kiln, so that the pulverised material fuses and surrounds the separate grains of refractory material (dolomite) with a non-cohesive coat. When the product is used for a granular lining of a furnace the fusible coating binds together the grains of refractory material to a permanent mass.

DIATOMACEOUS EARTH.—L. Kern (Hamburg) U.S. Pat. 1,206,546, Nov. 28th, 1916. Articles of diatomaceous earth are made by mixing the earth with hydrochloric acid (to form metallic chlorides), moulding and partly drying the product. and then burning so as to convert the metallic chlorides into oxides.

ARTIFICIAL BUILDING MATERIAL.—L. Kern (Hamburg), U.S. Pat. 1,206,545, Nov. 28th, 1916. Wet infusorial earth and fusible clay are mixed to give a product which melts at 650°—950° C. The mixture is moulded and pressed into bricks, which are dried in a current of air, burned, and then rapidly cooled. The resulting bricks are porous, fireproof, and of low specific gravity.

PLASTIC BINDING COMPOSITION.—J. G. Vail, U.S. Pat. 1,206,056, Nov. 28th, 1916. An emulsion is formed from an alkaline silicate solution and a bituminous product by equalizing the viscosities of the substances and then mixing them. The viscosity of the sodium silicate may be increased by incorporating stone screenings with it, and the viscosity of the bituminous product may be lessened by addition of a suitable solvent.

REFRACTORY PRODUCTS, ETC.—A. P. Taylor and J. D. Runyan, U.S. Pats. 1,212,846 and 1,212,847, Jan. 16th, 1917. In both cases calcined flint clay is used, after picking out visible impurities. In the first patent it is mixed with highly refractory kaolin and plastic kaolin, the mixture being shaped and burned in the customary manner. According to the second patent the selected flint clay is ready for use in the manufacture of refractory products.

PLASTIC COMPOSITION FOR FIREBRICKS.—E. V. Wagner, U.S. Pat. 1,209,784, Dec. 26th, 1916. The firebricks are made of a mixture of 100 lb. coal ashes, 2 lb. alumina, and 2—2½ gallons water.

COMPOSITION FOR TILES.—P. C. Boving, U.S. Pat. 1,210,756, Jan. 2nd, 1917. A mixture of ground burned clay, calcined magnesite, and magnesium chloride solution is made into paste, dried to a moist powder, and compressed in moulds to form tiles.

REFRACTORY BODIES.—H. F. Chappell, U.S. Pat. 1,226,750, May 22nd, 1917. Alunite is calcined and then leached, the product, with or without fireclay intimately mixed, being heated sufficiently to cause the material to bind together.

REFRACTORY BRICKS.—J. F. Léger (*Pat. J.*, No. 1,392, 1915). Pat. No. 12,987, May 27th, 1914. Refractory bricks, etc., are formed from a mixture of 1 part calcined magnesia, 1 to 20 parts granulated flint, and 1 to 10 parts powdered flint, bound with a solution of magnesium chloride.

PATENT METHOD FOR CASTING HOLLOW CYLINDRICAL WARE.—Joergensen (*Deut. Top. Zieg. Zeits.*, 64, 17, 1915). H.E.W.

PATENT FOR USE OF CARBORUNDUM PARTICLES IN FLOOR TILES, ETC., TO PRODUCE PERMANENT ROUGHNESS.—Utzschnsider and Jaunez (*Deut. Top., Zieg. Zeits.*, 64, 17, 1915). H.E.W.

PATENT FOR PREVENTION OF CROOKED RIMS IN THIN PORCELAIN HOLLOWWARE.—Carl Herzog (*Deut. Top. Zieg. Zeits.*, 64, 18, 1915). H.E.W.

PATENT FOR MANUFACTURE OF FIREPROOF AND ELECTRICALLY RESISTANT WARES FROM MICA, WITH CLAY AS A BINDING MATERIAL.—(*Deut. Top. Zieg. Zeits.*, 100—1, 38, 1915). H.E.W.

IV.—SHAPING AND MOULDING. DRYING.

SHAPING POTTERY INSULATORS, ETC.—H. L. Doulton and W. Podmore (*Pat. J.*, No. 1,415, 1916). Pat. No. 21,923, Nov. 3rd, 1914. Relates to tools for boring and grooving insulators.

SHAPING POTTERY.—H. L. Doulton and W. Podmore (*Pat. J.*, No. 1,417, 1916). Pat. No. 22,757, Nov. 19th, 1914. A machine for shaping pottery, particularly insulator blanks. It consists of a horizontal work-holding shaft capable of revolving, and a tool shaft, which can be moved longitudinally and angularly (by a handle) to bring different tools successively on to the work.

POTTERY INSULATORS, ETC.—H. L. Doulton and W. Podmore (*Pat. J.*, 1,467, 1917). Pat. No. 102,994, Jan. 11th, 1916. Addition to 22,757/14.

SHAPING POTTERY INSULATORS, ETC.—H. L. Doulton and W. Podmore (*Pat. J.*, No. 1,428, 1916). Pat. No. 100,261, April 17th, 1915. An addition to 21,923/14.

SHAPING POTTERY INSULATORS, ETC.—H. L. Doulton and W. Podmore (*Pat. J.*, No. 1,438, 1916). Pat. No. 5,757, April 17th, 1915. A machine for shaping telegraph insulators, etc., internally.

ELECTRIC INSULATORS.—Brown, Boveri, & Co. (*Pat. J.*, No. 1,437, 1916). Pat. No. 5,511, April 22nd, 1915. Relates to composite sleeve insulators.

ELECTRIC INSULATORS.—J. Sayer (*Pat. J.*, No. 1,490, 1917). Pat. No. 107,006, May 26th, 1917. Electric insulators of porcelain, etc., are strengthened by a reinforcing element or core having a number of laterally disposed arms.

ELECTRIC INSULATORS.—Taylor, Tunnicliff & Co., and P. Cooper (*Pat. J.*, No. 1,500, 1917). Pat. No. 108,821, Mar. 16th, 1917. The interiors and lower ends of the telegraph and like insulators are shaped or turned by a series of tools successively brought into use by the longitudinally traversing turret head of any known or suitable lathe. The tools comprise a boring-tool for the central recess, a grooving tool for the annular recess between the petticoats, and a stepped tool for shaping the end of the insulator. A stepped tool for shaping the end of the insulator before forming the annular groove is figured.

DOLLS.—M. Pontio (*Pat. J.*, No. 1,498, 1917). Pat. No. 108,490, Aug. 3rd, 1917. Dolls' heads and bodies are prepared by moulding from a composition of casein and gelatine, or gelatine alone, mixed with talc, kaolin, gypsum, flake white, whitening, or other mineral powder, gum arabic or other gum or glue being added if desired. The composition is rendered insoluble either before or after moulding by immersion in formaldehyde, etc. Colouring matter may be added.

FINISHING AND HANDLING CUPS, ETC.—E. Brookes (*Pat. J.*, No. 1,449, 1916). Pat. No. 9,597, July 1st, 1915. The cup or mug, etc., made slightly too deep, is cut down to proper size, while rotating, by the blade of a tool, and the cut edge is trimmed by another tool. The separately cast handle, after being trimmed as described in Specification 100,231 (of same date as above) is applied to the correct position by a special contrivance.

THROWING AND TURNING.—E. Brookes (*Pat. J.*, No. 1,474, 1917). Pat. No. 18,012, Dec. 24th, 1915. Relates to a lathe and tools for operating on cups, mugs, etc., in a semi-plastic condition previous to baking, to true them up if made in two parts, cut or trim the edges, and smooth the seams.
HANDLES FOR CAST CUPS, JUGS, ETC.—E. Brookes (*Pat. J.*, No. 1,428, 1916). Pat. No. 100,231, July 1st, 1915.

CASTING POTTERY.—E. Brookes (*Pat. J.*, No. 1,474, 1917). Pat. No. 103,851, Feb. 10th, 1916. An apparatus for delivering measured quantities of clay slip into moulds used in the casting of pottery comprises a tank supplied from a pipe through a ball-cock maintaining a constant level of liquid in the tank, and a series of open-topped pipes forming measuring chambers, the supply to and discharge from the pipes being controlled by cocks connected by links to a sliding frame, whereby simultaneous filling and discharge is effected.

THROWING POTTERY.—F. Hancock (*Pat. J.*, No. 1,413, 1916). Pat. No. 21,472, Oct. 24th, 1914. The exterior surfaces of basins, jars, electric fittings, teapots, cups, etc., are shaped while rotating on a chock of a lathe or on a jigger spindle by a skeleton profiling-tool. The rim and any grooves are shaped by special tools.

THROWING AND TURNING.—F. Hancock (*Pat. J.*, No. 1,452, 1916). Pat. No. 11,048, July 30th, 1915. An article such as an insulator, basin, etc., rotating under a tool, when lowered from the tool rests on an inner auxiliary chuck, the spindle of which lies loose in a central boring of the jigger-shaft. It can thus be slowed down by hand and removed without stopping the jigger-shaft.

POTTERS' AND OTHER LATHES.—T. Taylor (*Pat. J.*, No. 1,433, 1916). Pat. No. 100,431, Jan. 26th, 1916. Reference is made to the lathe described in Pat. No. 26,534/12.

MOULDING PLASTIC SUBSTANCES. CLAY-EXTRUSION MACHINE. —J. Hall (*Pat. J.*, No. 1,433, 1916). Pat. No. 4,183, Mar. 17th, 1915. Used for earthenware gullies, etc.

MOULDING HOLLOW-WARE.—J. W. Hartley and C. Bailey (*Pat. J.*, No. 1,431, 1916). Pat. No. 3,391, Mar. 3rd, 1915. Relates to a mould for cups, mugs, jugs, etc., and especially for articles which leave the mould complete with handles as described in Specification 15,308/14.

MAKING POTTERY.—J. Brewin (*Pat. J.*, No. 1,451, 1916). Pat. No. 10,643, July 22nd, 1915. Salt-glazed stoneware pipes, gullies, traps, etc., are made by adding dry clay dust to the soft puffed clay before using, to prevent blisters drom rising during drying.

POTTERY-MAKING.—F. G. Haney (*Pat. J.*, No. 1,458, 1916). Pat. No. 12,705, Sept. 4th, 1915. Clay, issuing through a removable die or former at the bottom of a hopper, is cut off in lumps of uniform size and shape by means of a reciprocating cutter, and deposited on a small table, whence it is swung across on to one of a series of four moulds held on a revoluble table. This table receives automatically a quarter-turn each time the small table receives a fresh lump of clay.

CASTING POTTERY.—W. Illingworth (*Pat. J.*, No. 1,469, 1917). Pat. No. 103,192, Feb. 10th, 1916. Moulds for casting pottery are formed with casting apertures at the top and bottom, so that whilst the bottom apertures are draining the top may be filled.

BOTTLE-MAKING MACHINES.—J. H. Steele (*Pat. J.*, No. 1,461, 1917). Pat. No. 13,703, Sept. 27th, 1915. Relates to machines for making bottles, jars, etc., which comprise a number of arms intermittently rotatable in a horizontal plane, and consists of means for locking the arms in the desired position and without shock.

STONEWARE AND LIKE BOTTLES, ETC.—G. W. Cheavin and H. W. Rathbone (*Pat. J.*, No. 1,478, 1917). Pat. No. 104,945, April 3rd, 1916. Bottles and other articles of stoneware and earthenware of rectangular or other angular shape are produced by drawing or squeezing a circular article (produced on the potter's wheel) through a frame or die.

SHAPING EARTHENWARE JARS, ETC.—H. Oakes and J. Bailey (*Pat. J.*, No. 1,474, 1917). Pat. No. 17,979, Dec. 24th, 1915. Jars, pots, etc., with contracted necks are shaped between internal and external knives or tools, which are in operation throughout the forming process. The ware may be partly shaped within a mould, the external tool acting upon the projecting upper part; or the whole of the article may be shaped between the knives. The external tool is pivoted upon pins in a bracket.

SHAPING EARTHENWARE.—H. Oakes (*Pat. J.*, No. 1,493, 1917). Pat. No. 107,688, Aug. 16th, 1916. The clay rotates on a wheel or in a mould from which it protrudes, and is formed into the article by an external roller and an internal roller, or several of each. The rollers are mounted so as to be independently operated and adapted to be swung to or clear of the work. Specification 17,979/15 is referred to.

MOULDING PORCELAIN OR EARTHENWARE.—E. D. M. Scrivener and P. Cooper (*Pat. J.*, No. 1,478, 1917). Pat. No. 105,052, Dec. 30th, 1916. In moulding articles such as insulators two concentric members remain pressed against the ends of the article by springs while the plungers—consisting of annular parts—are being withdrawn.

BRICK-MAKING MACHINES.—G. A. Hodson (*Pat. J.*, No. 1,419, 1916). Pat. No. 23,303, Nov. 30th, 1914. Relates to a modified finishing-die.

MOULDING FIREBRICKS.—M. Curry and W. O. Wood (*Pat. J.*, No. 1,458, 1916). Pat. No. 12,756, Sept. 6th, 1915. Firebricks are formed by moulding or pressing them in a mould against the action or reaction of spring pressure. One form of apparatus is figured.

ROOFING-TILES.—R. Y. Ames and W. Haywood (*Pat. J.*, No. 1,494, 1917). Pat. No. 107,847, Aug. 7th, 1916. Rodfing-tiles of the Italian or Roman type are provided on the lower series with lateral projections which engage battens, cleats, or blocks secured to the roof. The lower tiles when flat are tabbeted to interlock, and the upper or roll tiles are nailed to the cleats and their ends overlap. The lower tiles may be curved, the tiles in both series being tapered from end to end so that contiguous tiles interlock and the projections of the lower tiles form supports for the tile during manufacture.

BRICKS AND BUILDING BLOCKS.—A. Tuck and W. A. Adlam (*Pat. J.*, No. 1,491, 1917). Pat. No. 107,338, Dec. 5th, 1916. Relates to special shapes.

PRESS DIES FOR TILES, ETC.—T. F. C. Gosling and W. Boulton, Ltd. (*Pat. J.*, No. 1,493, 1917). Pat. No. 107,535, Jan. 2nd, 1917. In dies for tile and like presses, such as are described in Specification 6,333/15, the shaping face of the top die remains in contact with the tile until it is delivered, thereby preventing suction and deformity or damage to the tile.

DRYING WARES OF TENDER CLAY.—R. O. Perrott, U.S. Pat. 1,215,849, Feb. 13th, 1917. A multi-tunnel dryer with one end highly heated and the other end adapted for gradual drying, a forced draught being used throughout. The temperature and pressure is controlled in each section of the dryer.

DRYING CLAY ARTICLES.—F. A. Secord, U.S. Pat. 1,221,383, April 3rd, 1917. Currents of cold air are passed through a closed casing containing the clay articles. The temperature of the air currents is afterwards raised considerably, and they then remove moisture from the surfaces of the clay and from the casing.

V.—FIRING KILNS, OVENS, MUFFLES, ETC.

CRUCIBLES, MUFFLES, ETC.—F. Garros (*Pat. J.*, No. 1,422, 1916). Pat. No. 24,501, Dec. 22nd, 1914. Ceramic products, for example, crucibles, glass melting pots, muffles, saggars, etc., containing plumbago, ground retort carbon, or other combustible substance, are protected from rapid combustion by a covering of enamel, or by mixing the plumbago, etc., with vitrifiable ceramic material, for example, porcelain paste.

SHAFT KILNS.—J. A. Owen (*Pat. J.*, No. 1,428, 1916). Pat. No. 2,003, Feb. 8th, 1915. Addition to 14,959/14. The conical air-supply member is modified so that air at atmospheric pressure and air under forced draught are independently delivered to the kiln.

CERAMIC KILNS.—W. A. Norman and E. Evans (*Pat. J.*, No. 1,437, 1916). Pat. No. 5,341, April 9th, 1915. The draught passages in the floor of a ceramic kiln are provided with shrouding-means for preventing accumulation of dust and rubbish in and around the passages. Several modifications of the arrangement are described.

SHAFT KILNS.—A. Giesecke and Konegen Co. (*Pat. J.*, No. 1,449, 1916). Pat. No. 9,609, July 1st, 1915. In a shaft kiln for burning lime, cement, dolomite, etc., the blast is introduced through nozzles arranged tangentially to a circle of less diameter than the shaft, the blast being thus kept away from the walls of the kiln.

SHAFT KILNS.—Steiger-Kraner & Co., and O. Frey (*Pat. J.*, No. 1,451, 1916). Pat. No. 10,338, July 15th, 1915. A rotary discharge device for boring into and breaking up the descending mass of material, associated with a charge support with outwardly tapering radial ribs.

FIRING TILES.—P. d'H. Dressler (*Pat. J.*, No. 1,457, 1916). Pat. No. 12,581, Sept. 1st, 1915. The tiles, stacked vertically in pairs, are supported upon the arrises of rods or saddle-backs of refractory material carried by walls built up of bricks as the tiles are stacked. Tiles of different sizes may be accommodated by suitably spacing the rods and arranging the bricks.

CRUCIBLE FURNACES.—A. Hermansen (*Pat. J.*, No. 1,468, 1917). Pat. No. 15,887, Nov. 10th, 1915. The furnace includes a crucible chamber into the middle of which opens a burner port communicating with a gas-producer below. The regeneratively-heated secondary air is supplied through passages delivering into and beneath the burner port respectively. The crucible chamber may be of circular or oval shape in plan, and in the latter case a number of burner ports may be situated side by side along its length.

POTTERY AND LIKE KILNS.—South Metropolitan Gas Co. and D. Chandler (*Pat. J.*, No. 1,453, 1916). Pat. No. 101,567, Jan. 19th, 1916. Relates to gas-fired multiple-chamber kilns, provided with two sets of burners which are used in succession. One set of burners delivers vertically into bags in the upper chamber, and the other burners deliver into a space in the floor of the same chamber. The products of combustion pass downward through the two chambers to a flue, whence they are led to a second kiln where goods are being dried. Three kilns are preferably worked in a series.

CRUCIBLE FURNACES.—R. Halkett (*Pat. J.*, No. 1,469, 1917). Pat. No. 103,232, April 20th, 1916. In a gas-fired crucible furnace, a closed circuit pipe having connexions with the burner nozzles is embedded in a permanent brickwork lining, the gaseous mixture delivered through the pipe being thus preheated and the supplies to the burner nozzles equalized. An inner protective porous lining may be made from a mixture containing 15 parts of fireclay or ball clay, and 1 part each of alumina and sawdust, to which is added 1 part of a solution of silicate of soda and 2 parts of water.

BRICK KILNS.—L. W. McArthur and P. S. McKergow (*Pat. J.*, No. 1,453, 1916). Pat. No. 101,583, Mar. 22nd, 1916. The kilns are open-topped, and chimneys form vertical extensions of the side walls and communicate with the kiln chamber by openings near its top.

BRICK AND LIKE KILNS.—L. W. McArthur and P. S. McKergow (*Pat. J.*, No. 1,491, 1917). Pat. No. 107,256, June 28th, 1916. An open-topped kiln heated by furnace beneath, the gases from which pass up into the kiln chamber through tortuous passages in the floor, is provided with take-off flues in the side walls near the top, these flues being arranged in series converging into chimneys placed at intervals along the side walls.

GAS-FIRED OVENS AND FURNACES.—D. Thomson, Ltd., J. Gallimore and D. Cook (*Pat. J.*, No. 1,470, 1917). Pat. No. 103,319, Jan. 17th, 1916. In ovens and furnaces heated by a multiplicity of gas burners, all the burners are controlled from a central point, so that the number of burners in use can be varied while maintaining a constant pressure of the gas supplied to each burner. Means are provided for indicating the number of burners in use. An igniting-burner is adapted to light all the burners of a series and itself be ignited by a single pilot burner. Interlocking means are provided to prevent the turning-on of the main burners until after the igniting-burner has been lit, while permitting the extinguishing of the lighting-burner when the main burner has been lit. One arrangement is figured.

SAGGARS.—W. L. Aynsley and G. Reynolds (*Pat. J.*, No. 1,484, 1917). Pat. No. 105,995, May 12th, 1916. The lower part of a wall of a round or oval saggar is pierced by holes to admit the flames or hot gases, and the upper part is cut away in places. In rectangular saggars the ends, sides or base are provided with perforations or slots.

SAGGARS.—W. L. Aynsley and G. Reynolds (*Pat. J.*, No. 1,485, 1917). Pat. No. 106,145, May 17th, 1916. The earthenware is placed for firing in frames consisting of a ring or horseshoe base and tubular pillars of circular section holding the thimbles The tubular pillars have stiffening ridges and are cemented in sockets on the base.

CRUCIBLE FURNACES.—I. Hall (*Pat. J.*, No. 1,489, 1917). Pat. No. 106,896, July 18th, 1916. In a solid fuel furnace an annular blast chamber is formed by an enlargement at the lower part of the furnace body, from which air passes through openings in the lining to the space beneath the annular grate, and thence through openings to the fire above the grate. The grate is supported on the closed bottom of the furnace.

CRUCIBLE FURNACES.—I. Hall (*Pat. J.*, No. 1,491, 1917). Pat. No. 107,286, Aug. 10th, 1916. An annular blast chamber is provided in a furnace adapted for solid fuel, and a door gives access to the spaces above and below the grate, being preferably constructed to form a segment of the blast chamber. The blast enters the blast chamber tangentially. A counterbalanced cover, capable of horizontal as well as vertical movement, is provided, and fitted with a small inspection cover.

FURNACES FOR CRUCIBLES, ETC.—H. N. Davis and W. R. Twigg (*Pat. J.*, No. 1,491, 1917). Pat. No. 107,263, July 6th, 1916. Oil and gas-fired furnaces for heating steel billets or ingots, crucibles, and the like, are constructed with a raised hearth or floor with channels beneath it, through which, as well as over the hearth, the flames and hot gases from the burners pass after deflection by the walls and roof of the furnace.

FURNACES FOR CRUCIBLES, ETC.—H. N. Davis and W. R. Twigg (*Pat. J.*, No. 1,491, 1917). Pat. No. 107,264, July 6th, 1916. The heating chamber of a furnace for heating crucibles, ingots, etc., is of frusto-conical form, and is fired by a burner delivering through a tangential opening at the lower and wider end. The chamber may taper uniformly or by steps, and

the crucible or ingot may be placed eccentrically in the heating chamber. The furnace cover consists of a block with a central aperture covered by a second block spaced from the lower one.

GLASS AND METAL-HEATING FURNACES.—H. N. Davis and W. R. Twigg (*Pat. J.*, No. 1,492, 1917). Pat. No. 107,433, July 6th, 1916. A gas or oil-fired furnace or glory hole for reheating articles or portions thereof during their manufacture has a tapered combustion chamber, into the larger end of which the flame enters tangentially. The outlet at the smaller end may also be arranged tangentially.

CRUCIBLE FURNACES.—T. W. Aitken (*Pat. J.*, No. 1,492, 1917). Pat. No. 107,468, Aug. 21st, 1916. Tuyeres which incline downwardly and spread laterally are provided at one or two levels above the combustion floor of a furnace burning solid fuel to distribute and soften the blast. The blast is preferably supplied through an annular casing, and the furnace is preferably mounted to tilt on trunnions. An inspection door is fitted opposite each tuyere.

BRICK, POTTERY, AND LIKE KILNS.—T. West and W. J. G. Lewis (*Pat. J.*, No. 1,493, 1917). Pat. No. 107,678, July 28th, 1916. A substantially open chamber is arranged below the perforated floor of the kiln chamber, and heating gases are supplied thereto by a plurality of flues running concentric with, or parallel to, the outer wall of the kiln, each flue receiving its gases from a plurality of firegrates. The kilns may be circular or rectangular.

CRUCIBLE FURNACES.—L. Hall (*Pat. J.*, No. 1,495, 1917). Pat. No. 108,084, Oct. 31st, 1916. The preheater of a melting furnace is constructed with a lining composed of two concentric annular portions connected together with a space between them, and preferably made in sections interengaging, and enclosed in a metal casing. The products of combustion pass through the annular space.

CRUCIBLE FURNACES.—P. Southwick (*Pat. J.*, No. 1,498, 1917). Pat. No. 108,566, Sept. 16th, 1916. In crucible furnaces burning solid fuel, an air-admission frame arranged above the grate level is constructed of slotted cast-iron bars mitred at the ends and secured together by dovetail connexions.

MUFFLE FURNACES.—Sir A. M. Duckham (*Pat. J.*, No. 1,498, 1917). Pat. No. 108,573, Sept. 25th, 1916. Relates to annealing ovens and the like of the kind in which there are on each side a series of combustion chambers and a waste-gas flue, with a number of cross-flues traversing the top of the muffle, those which lead from the combustion chambers on one side alternating with those that lead from the combustion chambers on the other. Gas and air are introduced to the combustion chambers through vertical passages arranged between the vertical flues which lead from the cross-flues to the waste-gas flues, and in proximity to the flues leading from the combustion chambers to the cross-flues. The air is preheated in a chamber above the muffle. A longitudinal passage connects the middle points of all the cross-flues.

CRUCIBLE FURNACES.—F. J. Grocott (*Pat. J.*, No. 1,498, 1917). Pat. No. 108,615, Nov. 24th, 1916. For the supply of steam to generate a combustible gas from the fuel within the furnace, water is supplied to trough-shaped channels forming firebars, or steam may be supplied directly to the furnace at the lowest zone; or both methods may be employed together. Heated air also is supplied at a single level or zone above the firebars.

GASEOUS-FUEL FURNACES.—Chillington Tool Co. and L. Nettleton (*Pat. J.*, No. 1,500, 1917). Pat. No. 108,939, Oct. 6th, 1916. The wall opening through which a combustible mixture is supplied from a burner nozzle to the working chamber is formed with flared ends and an intermediate straight portion, and the burner nozzle is fixed relatively to the flared end in such a position as to allow free escape of flame in the event of back-firing. The gas and air mixture passes into the intermediate straight part without touching the flared part, and burns in the farther flared part.

GASEOUS-FUEL FURNACES.—A. C. Ionides (*Pat. J.*, No. 1,499, 1917). Pat. No. 108,701, Aug. 11th, 1916. Crucible and other furnaces are heated by a gaseous mixture of air and fuel in self-burning proportions delivered by appropriate mixing devices to annular or elongated combustion chambers with narrow outlets through which the flames issue into the heating chambers. The products of combustion are discharged downwardly through conduits arranged to jacket the heating chamber. Figures illustrate a crucible furnace with annular combustion chamber, a rectangular heating-furnace, and a tall, tubular furnace with a series of superposed annular combustion chambers.

CERAMIC KILN.—A. L. Stevens, U.S. Pat. 1,223,440, April 24th, 1915. A continuous series of bag walls and flues extends all along each side of the kiln, and each unit communicates with a regenerator, and has also an inlet for fresh air. Hot air or gas from the regenerators passes alternately through the flues on opposite sides of the kiln and is discharged through flues on the other side into the corresponding generator.

MUFFLE KILN FOR ENAMELS.—E. Schröder, Ger. Pat. 296,457, Oct. 31st, 1915. The kiln is provided with a deep, narrow, circumferential flue extending beneath it. The sole of the kiln is built with two or more steps, and part of the kiln wall is made of carborundum or other material superior to fireclay as regards thermal conductivity. The flames thus play on each support for a short time only and the heat is not so severe as usual but is more uniformly distributed. Even if a support cracks it cannot choke the flue. The flue dust does not so easily attack the kiln walls and the muffles last longer.

TUNNEL KILN.—J. A. Reams, U.S. Pat. 1,223,732, April 24th, 1916. An open-ended tunnel is divided into zones connected by flues. Air is passed laterally across the kiln in the zone at the exit end, thence back across the tunnel in the form of products of combustion, thence again across the tunnel in another zone, and finally across the tunnel in a zone at the inlet-end.

SHAFT-KILNS.—G. Polysius, Ger. Pat. 296,155, March 17th, 1916. Magnesite, lime, cement mixture, etc., is charged into the shaft-kiln through a vertically superposed series of auto-feeders, the supply to each of which is shut off before its exit is entirely closed. A rotary hopper would be fitted with trippers to regulate the action of the exit slide of a primary supply hopper, and it is automatically closed by springs. In this way the admission of "false air" is prevented, as the material cannot become jammed between the slide and its frame so as to hinder complete closure.

KILN OR OVEN FOR BRICKS, ETC.—L. Kern (Hamburg), U.S. Pat. 1,206,547, Nov. 28th, 1916. A triple stage vertical oven has the three crowns perforated. The lowest stage forms the combustion chamber, and those above contain the goods to be burned. Dampers are arranged so as to distribute part of the heat round the sides of the burning chambers.

FURNACE LINING.—G. S. Davison, U.S. Pat. 1,210,431, Jan. 2nd, 1917. A furnace lining is made of granular, basic refractory material, the pores in the particles of which are impregnated with a small amount of siliceous and ferrugineous material, such as basic slag. The faces of the particles are substantially free from such siliceous material.

KILN CONSTRUCTION.—C. H. Zwermann, U.S. Pat. 1,216,590, Feb. 20th, 1917. The goods to be burned are placed in the centre of the kiln, being separated by partitions from the combustion chambers at each side. Connected with each combustion chamber is a series of lateral and vertical tubular flues. The inner and outer walls of the kiln are insulated from each other.

TUNNEL KILN.—C. Dressler, U.S. Pat. 1,225, 318, May 8th, 1917. This is a modification of English Pats. 18,114 and 28,617 (both in 1910). Besides the burner at one end of each chamber, there are sleeves, each with gas and air supply, for heating the combustion chambers at several other points.

BRICK KILN.—J. T. Underwood, U.S. Pat. 1,105,724, Aug. 4th, 1914. Reissue 14,251, Jan. 16th, 1917.

BRICK KILN.—C. E. Vredenburg and T. Lacey, U.S. Pat. 1,224,248, May 1st, 1917. The zone of fuel between the heads of the kiln is provided with a forced draught of air, which passes downward through the fuel. A separate forced draught is supplied laterally to the fuel below the head or heads, the two air currents being prevented from mixing.

KILN FOR CERAMIC MATERIALS, ETC.—J. T. Underwood and J. M. Justice, U.S. Pat. 1,224,978, May 8th, 1917. Gas and air are forced into the top of a kiln to be burned there. The outlet flue in the sole is restricted so that the internal pressure exceeds that outside the kiln, thus preventing draughts of cold air from entering.

TUNNEL MUFFLE FURNACE.—H. T. Padelt, Ger. Pat. 295,987, Nov. 24th, 1914. Applies to tunnel muffle furnaces for burning ceramic ware and heating metals, chemicals, etc. Heating flues built in, or adjacent to, the walls of the furnace are reduced in size from below upwards, and each flue can be heated separately. Air for combustion is preheated in similar flues in, or adjacent to, the walls of the cooling zone of the furnace; these flues connect with a common main flue, from which the air is distributed in different parts of the combustion zone.

KILNS FOR WARE.—A. B. Klay, U.S. Pat. 1,226,535, May 15th, 1917. The heating chamber has openings in the bottom and a corresponding series of flues in the top, the bottom openings being connected below with separate but interconnected furnaces. Along the length of the chamber a number of stacks communicate with opposite sides. The fuel is fed into the top of the chamber at a distance from the furnaces to which it passes.

PATENT CONTINUOUS FRIT KILN IN WHICH COMBUSTION GASES ARE LED TWICE OVER MATERIAL TO BE FRITTED, THENCE UNDER BED OF KILN TO CHIMNEY.—M. Berndt (*Deut. Top. Zieg. Zeits.*, 71, 22, 1915). H.E.W.

PATENT COMBINED KILN AND DRYING CHAMBER.—F. Rauls (*Deut. Top. Zieg. Zeits.*, 78, 28, 1915). H.E.W.

GAS FIRING AND THE GLASS INDUSTRY.—J. W. Cobb (*J. Soc. Glass Ind.*, 1, 223, 1917). In manufacture, coal forms the basis of all fuels used, and the application of gaseous fuels obtained from coal marks a distinct advance upon direct firing. In the old types of furnace, where the fuel is burnt close to its work, the heat available is only a small percentage of the whole, due to the fact that the fall in temperature of the flame from entry to exit is only small. There is great danger too, in the light ash which is formed, being carried forward to exercise its baneful effects as a flux on furnace linings, etc., and also its decolorising effects on any glass it may come into contact with. The waste heat from direct fired furnaces may be utilised, say for steam raising, but only in a makeshift manner. Attempts too, have been made to utilise this waste heat to preheat the air required for combustion, but owing to difficulties of furnace design these attempts are far from being successful. A fact often lost sight of in heating air by passing it through hot flues, is that the air is transparent to radiant heat and is only affected by actual contact with the hot walls of the flue. Thus preheating by passing air through hot flues of a large cross section is very ineffective.

A great step in furnace work was the introduction of the Siemens regenerative furnace. The action of this and other producers depends upon simple chemical and thermal principles. Coal is burnt away from the furnace proper with the formation of carbon monoxide. This latter gas is then delivered into the furnace together with air, and burning there to carbon dioxide, produces the heat required. In addition, the waste hot gases leaving

the furnace are made to pass through chambers filled with chequered brickwork, to which they yield their heat. By suitable means, the ingoing air and gas is afterwards passed through this hot brickwork and so is heated before entering the furnace, resulting in an enormously increased temperature of combustion. In addition the regenerative chambers serve as filters for the dust or ash in the gases.

The Siemens producer was described in detail, a series of lantern diagrams illustrating various points being shown.

In the Siemens producer the depth of fuel is large and there is considerable frictional resistance to movement of gas. Thus the rate of production is slow with ordinary draught. If the rate has to be increased air must be blown in, and this has its drawbacks. With a natural draught Siemens the heat evolved in the producer is small and easily dissipates. With forced draught this heat is much larger, and so the temperature rises to such an extent as to cause clinkering. In order to keep down the temperature near the firebars steam is blown in. The advantage secured by this is not confined to clinker prevention. The steam, acting on the red hot carbon, forms a mixture of carbon monoxide and hydrogen (water gas), and this mixture is a very valuable fuel in itself. Its production, too, is accompanied by an absorption of heat from the layer of hot coal near the firebars. Thus the blowing in of steam not only cools the producer and prevents clinkering, but it adds carbon monoxide and hydrogen to the producer gas without dragging in nitrogen, *i.e.*, the percentage of combustible gas is raised and the temperature realised finally is increased. It must be recognised that there are limits to the amount of steam that can be blown in. Any excess results in the formation of carbon dioxide, or may even pass into the furnace chamber unaltered, where it has the harmful effects of an inert gas. The best proportions of air and steam have to be determined by practice. Several modern gas producers were described and illustrated by lantern diagrams. Special details were given of the Taylor producer, the Kerpely producer, and of producers of the Mond type. The production of ammonia, low temperature regeneration, and the washing of producer gas by the Mond system were also discussed in detail.

The remainder of the paper dealt with the problems of recuperation, the heating of small furnaces, the use of town's gas, and the necessity of securing, if possible, gas of fairly constant composition.

VI.—GLAZES AND GLAZING. ENAMELS.

ENAMELLING.—E. J. Oakes (*Pat. J.*, No. 1,446, 1916). Pat. No. 8,849, June 16th, 1915. A machine for removing glaze, by rubbing, from the feet or bottoms of cups, teapots, etc., consisting of a drum covered with flannel or other suitable material, and rotating intermittently in a water trough. The articles are rubbed over the surface of the drum, the glaze adhering to it being removed by rotating the drum in the water.

ANTIMONATES FOR ENAMELS AND GLAZES.—P. Eyer (*Pat. J.*, No. 1,453, 1916). Pat. No. 11,083, July 30th, 1915. Antimonates of alkaline earths, aluminium, magnesium, zinc, tin, zirconium, beryllium, etc., for use as clouding agents for enamels and glass, are produced by heating a mixture of antimony oxide and a metal oxide with ammonium nitrate until the ammonium nitrate is all driven off. The metal oxide may be used in excess, or two or more metal oxides may be used; instead of oxides, compounds yielding oxides may be employed, such as carbonates. The products may be mixed with other clouding agents.

ENAMEL.—M. Mayer and B. Havas, U.S. Pat. 1,220,253, March 27th, 1917. An opaque white enamel is prepared by adding a mixture of titanic oxide and zirconium oxide to the enamelling material.

ENAMELS FOR IRON GOODS.—Koepp & Co. (*Pat. J.*, No. 1,440, 1916). Pat. No. 100,777, Feb. 18th, 1916. For enamelling iron goods, the usual fluxes, such as borax and boric acid, may be replaced by a comparatively large proportion of glass, preferably low-melting glass. The quartz and felspar in enamels may also be replaced by glass with clay to supply the alumina of the felspar; the clay also counteracts a reduced spreading power caused by the large addition of glass. The glass is advantageously used in conjunction with large amounts of alkaline silicate or bisulphate, etc. Glass may be melted with sodium carbonate, and the fused product used as a substitute for borax, quartz, and felspar in the enamel mixture. With large quantities of glass, the natural compounds termed boric lime, like borocalcite, colemanite, boronatrocalcite, and boracite, may be used instead of borax. The quantity of glass to be added must be found by trial, and sometimes the quantities of other lime-containing constituents need to be reduced. The presence of the glass diminishes the injurious effects of salts (chlorides, sulphates, etc.) in the boric lime. Enamels prepared from boric lime adhere firmly, probably owing to an etching action of the impurities.

ENAMELS.—R. Koepp & Co. (*Pat. J.*, No. 1,448, 1916). Pat. No. 101,221, Aug. 16th, 1916. A clouding agent for enamels is zirconium borate supersaturated with oxide, for example, a product of the composition $ZrO_2.2B_2O_3 + 4ZrO_2$. The materials are preferably fused with cryolite or other alkaline fluoride. By adding saltpetre or other oxidizing agent, raw zirconia may be employed. For example, 70 parts raw zirconia, 30 parts boracic acid, 20 parts cryolite, and 50 parts saltpetre are thoroughly mixed together and fused, the cooled product being ground very fine.

ENAMELS.—R. Koepp & Co. (*Pat. J.*, No. 1,456, 1916). Pat. No. 101,802, Feb. 18th, 1916. Relates to the use of natural compounds like borocalcite, colemanite, etc., glass being also added. The quartz or felspar normally present in the enamel is replaced by clay and glass. The glass employed preferably contains a high percentage of alkali; ordinary commercial glass may be enriched with alkali by melting it with suitable alkali salts, such as carbonate, silicate, or bisulphate and coal. The glass may also contain boron, lead or fluorine compounds. Water-glass may be employed. Specification 100,777 (Feb. 18th, 1916) referred to.

ENAMELS.—R. Koepp & Co. (*Pat. J.*, No. 1,492, 1917). Pat. No. 107,392, Mar. 28th, 1916. Relates to ground enamels in which oxides of cobalt and nickel are employed to secure adhesion, and consists in replacing the pure oxides wholly or partly by ores of the metals, preferably those containing the oxides or carbonates, *e.g.*, New Caledonian ores. The ores should be free from sulphur and arsenic, which constituents may be removed by lixiviation. Ores poor in cobalt and nickel are used with pure oxides, or mixtures of different ores may be used.

SANITARY SPRAYING CHAMBER.—H. D. LILLIBRIDGE, U.S. Pats. 1,223,809 and 1,223,810, April 24th, 1917. A closed chamber is fitted with a spray, with means for circulating air, with an absorbent curtain or film of flowing liquid to receive surplus matter, and with means for withdrawing air from near the top of this curtain so that the work may be performed without risk of inhaling the sprayed material.

PATENT TILE-GLAZING MACHINE.—A. Baarmann (*Deut. Top. Zieg. Zeits.*, 71, 22, 1915). H.E.W.

VII.—COLOURS & DECORATIVE PROCESSES.

COATINGS WITH METALLIC APPEARANCE.—Jacob Brothers, Ger Pat. 295,627, Feb. 13th, 1914. A method of producing the appearance of brass, copper, tin, and other metals on enamelled ware.

COLOURED TRANSFERS.—R. S. Bennett (*Pat. J.*, No. 1,461, 1917). Pat. No. 13,764, Sep. 28th, 1915. Transfers for decorating pottery, etc., are printed in colours from an engraved intaglio plate at one impression, by inking the plate on different parts with the required colours by means of a series of stencil plates separately applied and each having openings corresponding to one colour. The ink may be applied through the openings by hand or by a special device figured.

TRANSFERS.—L. Brindley (*Pat. J.*, No. 1,467, 1917). Pat. No. 15,442, Nov. 2nd, 1915. Transfers for ornamenting earthenware, china, glass, or enamelled ware are made by first printing the design in one or more colours upon tissue-paper, applying the printed surface of the tissue-paper to the gummed surface of a duplex paper, and then softening and removing the tissue-paper. In practice, a plate engraved with the design is coloured, and the excess colour removed. The tissue-paper is then placed on the design, and the whole passed through a roller press and then placed on a hot stove for a short time. The paper is then drawn off and placed on the gummed duplex paper. After a short interval, the tissue is softened by rubbing with a mixture of suitable oils, such as linseed oil and oil of turpentine, and then removed, leaving the print on the duplex paper.

TRANSFERRING DESIGNS.—E. Entwistle (*Pat. J.*, No. 1,491, 1917). Pat. No. 107,347, Jan. 9th, 1917. In transferring designs such as friezes, borders, panels, etc., to painted walls or like surfaces in known manner by means of transfers from which the usual outer coating of gum or adhesive is omitted, an adhesive varnish of resin and turpentine being first applied to the wall or surface, the varnish for forming the adhesive coating consists of 4 oz. of powdered resin dissolved in 1 gill of turpentine. The damped transfer is applied to the tacky coating, and after removal of the paper and washing the transferred design may be varnished over.

TRANSFER PRINTING IN SEVERAL COLOURS.—J. C. Bailey and J. E. Brindley (*Pat. J.*, No. 1,497, 1917). Pat. No. 108,442, April 13th, 1917. A transfer for decorating pottery or earthenware, or for other purposes, is produced by transferring prints to a zinc plate previously coated with wax, attaching a sheet of transfer paper to the print by means of a gumming solution composed of white dextrine, glycerine, ox-gall, and water, and then detaching the transfer by heating the zinc plate preferably by the direct application of steam to the back of the plate.

METALLIC COATING FOR STONES.—E. Abeles, Ger. Pat. 295,607, June 19th, 1915. A method of covering natural and artificial stones with coatings of copper or other metal.

METHOD OF PRODUCING BLUE LUSTRES FROM COBALT WITHOUT THE USE OF GOLD.—E. R. Eichler (*Deut. Top. Zieg. Zeits.*, 72—3, 315, 1915). H.E.W.

VIII.—COSTS, MANAGEMENT, ORGANIZATION COMMERCIAL REPORTS.

STANDARD FACTORY ORGANIZATION.—(*Engineering*, 104, 377, 1917). In any trade there is no direction in which general agreement is more desirable than in that of costing and estimating.

Papers recently read before the members of the North-East Coast Institute of Engineers and Shipbuilders make it evident that the engineering trade is alive to the possibilities of a wider dissemination of the fundamentals of progressive trading. The following notes are offered as suggestive solutions

of some of the problems involved in connection with the financial organization of factories. (The full papers may be consulted in *Cassier's Engineering Monthly* for December, 1916, and January, 1917).

The main objects of compiling production costs are:—

1. To obtain a basis from which estimates for future productions require to be made.
2. To check any excesses that may occur.
3. To indicate where savings may be effected.

Briefly, cost accounts are for the purpose of future estimate, improvement, and effort. The interdependence of the trading and cost accounts may be sufficiently effected by opening records in the trading accounts to represent different productions, for instance—separate accounts for each process, class of manufactures or contracts, or in the case of similar productions—if convenient —accounts for grouping a number of processes, manufactures, etc. Arranging the trading accounts in this manner provides a check assuring the accuracy of the cost accounts, and shows the correct value of "work in progress" (stock). The entries in each trading account should only record direct purchases, stock used, and wages paid—the figures of each of these being shown separately, so that statistics which may be needed for various purposes may be secured without having to refer to the details in the cost accounts. Beyond providing information proving the accuracy of the cost accounts, the amount of work in progress and for subsidiary requirements, there is no practical advantage to be derived by extending the use of double entry methods between the cost and trading accounts.

Production Unit.—Having decided the lines upon which the cost accounts are to be kept, and the extent to which they are to be made to agree with the trading accounts, the next question is the method of measuring output. The capacity to produce is generally considered to be in proportion to the amount of labour employed—either in hours worked or wages paid. Both time and wages are subject to frequent fluctuations, and a better standard of output capacity is to fix a unit of production based on the first cost of manufacture. The unit is then a constant quantity.

The production unit will depend upon the amount of money spent upon labour, and may be fixed at 1d. or a multiple of 1d.—for instance, if it takes 12d. to produce an article for the first time, the production may be taken to represent 12 units costing 12d. If the cost of repeating equal output is reduced, say, to 9d., the units of production remain 12, produced at 9d., and so on.

The production units of each department, or each section, of the work to be done can of course be reckoned separately. In the case of an estimate involving an increase of work, for which the amount of production units have not been fixed, the extra units may be taken as equal to the extra estimated cost, and as the work proceeds the cost of the additional work should fix the amount of the new production units. A graphical record can then be prepared to show the actual units produced and the equivalent cost as the work progresses. The differences, if any, between the extra estimated production units and the extra cost production units cannot be avoided or recovered, and therefore only serve as a check on the estimate on the completion of the work.

Apportionment of "Establishment Expenses" (On-cost).—This item presents the greatest difficulty in arriving at "production costs." Various plans have been tried, each no doubt justified by certain considerations and open to equally sound objections. The "machine rate" occasionally employed in connection with engineering works is a case in point. If a machine can be used regularly doing work of constant value, a machine rate for distributing on-cost may be satisfactory, but there are few producing concerns that could maintain this condition. Irregular and variable employment is more general, and in these circumstances any attempt to apportion the total establishment expenses on this basis must take into account many elements of uncertainty and therefore introduce complications too cumbersome for practical purposes.

"*Permanent Charges.*"—Ground, buildings, plant and machinery, administration and permanent staff, advertising and travelling. Each of these expense items, though more or less a standing charge, differs in each depart-

ment, in relation to output, according to conditions of production. It is therefore more convenient to slump the lot, and decide a fixed rate of distribution based on normal output, at which rate allocation should be made in proportion to production units for any period.

Fluctuating Charges.—Building repairs, plant repairs, loose tools upkeep, indirect labour, stores consumed in the course of manufacture and material scrapped should increase or decrease in the same ratio as the production units, but as these charges are frequently subject to irregular variations they should be entirely allocated as they occur (say, monthly), so that they can be scanned and accounted for immediately any change takes place. It does not follow that the distinction between permanent charges and fluctuating charges makes it necessary to use two rates in apportioning on-cost. One rate, made up of a fixed figure (permanent charge) plus a changing figure (fluctuating charge), is sufficient.

Overtime and Night Shift Allowances.—These extra labour payments, which arise from such causes as purchaser's desire for early delivery, orders in excess of normal capacity, increased output, etc., vitiate the normal cost of production and should therefore be recorded separately; the records should be arranged to show this class of expenses against the order in connection with which it has been incurred.

The increased output due to overtime and night work does not involve a corresponding increase of on-cost. Permanent charges only increase to a limited extent in respect to depreciation and additional staff. The factor of depreciation may be ignored, as depreciation is more a question of age than of use, and additional staff may be almost entirely included in the records of overtime and night shift allowances. It is therefore only really in respect of fluctuating charges that overtime and night work create on-cost, and the amount of this should be nearly constant.

The amount of output (expressed in production units) due to overtime and night shift work should be shown in the records of overtime and night shift allowances. The ratio of overtime and night shift allowances to production units can then be determined, and if approximately equivalent to the ratio of permanent charges to production units of ordinary day output, should be dealt with in the same way, namely, by fixing a definite rate of apportionment. The ratio of overtime and night shift allowances to production units will probably exceed the ratio of permanent charges to production units of ordinary day output. If so, the difference should be arrived at and used to decide the extra expenses involved in doing work under overtime or night shift conditions.

The absence of anything approaching general agreement on the subject of estimating and costing has been largely due to conservatism originating with the management and transmitted to officials. Practically all initiative has been suppressed, so little progress has been made towards adopting new ideas. The manner of preparing cost records has to a large extent become obsolete, and continues to vary considerably. The financial accountant in his view of costing becomes too academic, and the technical man is handicapped by inexperience. There is no doubt about the necessity of specialising in this direction, and one who has done so must be the most efficient person to control the costing department. There appears to be considerable doubt as to whether and to what extent the accountant (to whom reference is usually made) or technical man should be the organizer of this department. The technical man is certainly the best judge of what factors require to be taken into consideration in preparing an estimate, and therefore must know best the kind of data required which should be provided. The financial accountant, on the other hand, requires the cost records to square with the financial accounts. Neither the estimator nor the financial accountant is sufficiently acquainted with the requirements of the other to make arrangements which will satisfy the necessities of both departments, and so an intermediary department suggests itself, namely, cost accounting, controlled by an official who should be familiar with works routine, estimating requirements, and the preparation of financial accounts, and who therefore must be trained in an engineering establishment [in the case under consideration]. The cost accountant should have a position

distinctly separate from that of either the estimator or the financial accountant, and his department should supply the cohesive element between these two. The cost accountant should be responsible for the organization of the stores and timekeeping departments, so that the necessary records for the use of the estimator and financial accountant may be arranged to meet the joint requirements of these departments.

As many items as possible should be charged direct to cost, so as to reduce the items which can only be charged arbitrarily. There is a tendency too often to follow the "law of average"—a polite way of describing "the rule of thumb"—in costing. The machine rate is an instance of direct charge, which disposes of items of general expense—sometimes justifiably. The items under the head of rating of machines should not in general practice include any expense other than interest and depreciation. Floor area, power and maintenance, which are sometimes included in machine rates, cannot be even approximately decided in respect of each machine.

It is a common practice to include in the prime cost records every item of expenses which may be incurred in connection with specific production; for instance, many firms charge the extra allowances paid for overtime and night shift work to the jobs upon which these allowances have been incurred; and to estimate the cost of repeat jobs from average cost records. Whether averaging is adopted or whether records made under varying conditions are used to estimate the cost of repeat jobs, the results must involve considerable speculation, and in any case procedure of this kind is tantamount to working backwards. Normal cost records are surely a more definite basis, for upon these the effect of any change of circumstances can be estimated more accurately. Another reason in favour of building up an estimate from normal records is that in the case of production under overtime or night shift conditions the relative amount of on-cost may be different from that of ordinary time conditions; in other words, another fluctuating element is introduced.

X.—GLASS.

GLASS MANUFACTURE.—T. J. L. Craig and P. Spence & Sons (*Pat. J.*, No. 1,413, 1916). Pat. No. 21,231, Oct. 20th, 1914. The siliceous residues from the treatment of bauxite or other aluminous ores, china clay, or calcined coal measure shales with sulphuric acid for obtaining aluminous compounds are utilized for making glass. The residues are mixed with lime, etc. Sodium carbonate to neutralize the acid, and other materials may be added.

GLASS-BLOWING, SHEARING, CUTTING, ETC.—J. Gray (*Pat. J.*, No. 1,414, 1916). Pat. No. 21,723, Oct. 29th, 1914. A machine for producing thin hollow glass-ware, such as electric lamps, tumblers, and lamp chimneys, by pressing and blowing. The machine comprises a single severing and pressing mechanism, and a number of units each composed of a moulding and blowing mechanism capable of rotating independently about a common axis.

GLASS-BLOWING.—W. J. Hasekamp (*Pat. J.*, No. 1,415, 1916). Pat. No. 21,826, Oct. 31st, 1914. Relates to a device for supporting blowpipes while they are cooling.

GLASS-BLOWING.—General Electric Co., Schenectady (*Pat. J.*, No. 1,421, 1916). Pat. No. 24,287, Dec. 18th, 1914. Relates to apparatus for removing the residue or moil from the ends of a blowpipe.

GLASS-BLOWING.—W. Forster (*Pat. J.*, No. 1,444, 1916). Pat. No. 7,969, May 29th, 1915. Relates to modifications of the bottle-blowing machines of Specification 24,927/01.

GLASS-BLOWING.—A. E. Clegg (*Pat. J.*, No. 1,432, 1916).—Pat. No. 3,809, Mar. 10th, 1915. Relates to a hand-operated blowing machine.

GLASS-BLOWING. BOTTLE-MAKING MACHINES.—J. H. Steele (*Pat. J.*, No. 1,437, 1916. Pat. Nos. 5,332 and 5,333, April 9th, 1915.

GLASS-BLOWING.—J. H. Steele (*Pat. J.*, No. 1,472, 1917). Pat. No. 17,378, Sept. 27th, 1915. Relates to machines for making bottles, jars, etc., which comprise a number of arms intermittently rotatable in a horizontal plane, and consists of means for adjusting horizontally the finishing-mould tables on the arms to which they are pivoted, so that the moulds may be registered with the neck moulds.

SHAPING GLASS BY ROTATION.—Schott & Co. (*Pat. J.*, No. 1,439, 1916). Pat. No. 6,309, April 28th, 1915. Relates to a method of smoothing the end surfaces of hollow glass bodies by rotating the article and pressing a tool against the softened surface (see Specification 2,330/87). According to the present invention, the glass body is allowed to cool, and only the surface to be smoothed is softened, as by a small blowpipe flame.

ANNEALING GLASS BOTTLES, ETC.—C. S. Dayton (*Pat. J.*, No. 1,442, 1916). Pat. No. 7,347, May 15th, 1915. Relates to apparatus for conveying bottles, etc., from the forming machine into the annealing oven or leer.

GLASS-DRAWING.—H. T. E. Kirkpatrick (*Pat. J.*, No. 1,446, 1916). Pat. No. 8,673, June 11th, 1915. Relates to the method of forming glass into sheets or cylinders by drawing it from a molten mass, and consists in surrrounding the drawing conduit by a second conduit, and in causing air to pass down the drawing conduit and up the second conduit, whereby the glass is cooled at the place at which it is gathered, and an even distribution of temperature along the length of the glass is secured.

GLASS MANUFACTURE.—R. G. Kann (*Pat. J.*, No. 1,451, 1916). Pat. No. 10,446, July 19th, 1915. Material for making glass is formed into briquettes, each briquette containing either a definite quantity of a number of ingredients or a definite quantity of a single ingredient. The proper number of briquettes is introduced into the melting pot, and separation of the ingredients is thus prevented. Special contrivances are employed for conveying and mixing the materials, etc.

DRAWING SHEET-GLASS.—Toledo Glass Co., Ohio (*Pat. J.*, No. 1,466, 1917). Pat. No. 15,134, Oct. 26th, 1915. The side portions of the metal, which form the edges of the sheet, are kept cooler than the middle part, and at the same time more drawing power is applied to the edges of the sheet.

SAWING GLASS, PRECIOUS STONES, ETC.—W. Taylor (*Pat. J.*, No. 1,467, 1917). Pat. No. 15,374, Nov. 1st, 1915. Means are provided for regulating the force applied to the taps or saws (charged with diamond or abrasive), so as not to damage the glass or saw when the saw is blunt.

DELIVERING MOLTEN GLASS, ETC.—L. A. Drey (*Pat. J.*, No. 1,468, 1917). Pat. No. 15,793, Nov. 9th, 1915. Relates to devices for delivering measured quantities of glass in drops, and consists in providing at the outlet of a furnace or crucible a heated chamber in which the drop accumulates, the chamber being closed by a cutting device and being of such a size that the drop, while accumulating, is at no time in contact with the walls, so that the formation of streaks and chill marks is minimised. The cutters are opened to discharge the glass and, when closed, sever the neck of the glass above the drop. One of the cutters is of hard, and the other of relatively soft metal.

ANNEALING GLASS.—H. J. F. Strandh (*Pat. J.*, No. 1,471, 1917). Pat. No. 17,038, Dec. 3rd, 1915. Relates to a cooling or annealing device in which the heated ware is transported on carriages or "boards" through the stove, and consists in providing the boards and some or all of the races in which they run with rollers, and also in providing a race at each end of the stove for moving the boards in or out of the stove.

GLASS-BLOWING.—G. C. Ryle (*Pat. J.*, No. 1,467, 1917). Pat. No. 15,625, Nov. 5th, 1915. A machine for making glass bottles, jars, etc., has two sets of moulds carried on separate rotating tables, and the parisons are transferred from one set to the other by a gripper which passes down through the finishing mould and lifts a parison up into the finishing mould from a parison mould.

GLASS-DRAWING AND CUTTING.—Window Glass Rotary Pot C. (*Pat. J.*, No. 1,474, 1917). Pat. No. 18,126, Dec. 29th, 1915. Relates to a drawing apparatus in which a rotating hearth supports a number of pots which are successively brought to stations for receiving and preparing the batches of glass. The degree of movement of the hearth and the heating of the furnace are automatically controlled by the hearth, the fuel supply being cut off during the passage of a pot from one station to the other.

JOINING GLASS SURFACES, ETC.—A. Hilger, Ltd., F. Twyman, R. G. Parker, and H. J. Dalladay (*Pat. J.*, 1,469, 1917). Pat. No. 103,233, April 20th, 1916. Glass or silica-glass surfaces are joined together in the manufacture of prisms, lenses, etc., for use in optical instruments, by cleaning the surfaces, pressing them together in optical contact, and then submitting them to a temperature high enough to cause them to join without causing permanent distortion. Thus in the case of a glass with melting point 1,100° C. and annealing point 600° C., the cleaned surfaces are clamped together in optical contact under a pressure of 15 lb. per sq. in., and the optical cell maintained for two hours at 500—520° C.

GLASS FURNACES.—L. Steelman (*Pat. J.*, No. 1,443, 1916). Pat. No. 100,899, Feb. 8th, 1916. Relates to annealing furnaces with special arrangements of flues for gas and air, etc.

MOULDING GLASS UNDER PRESSURE.—A. J. Bennett (*Pat. J.*, No. 1,434, 1916). Pat. No. 100,463, Feb. 24th, 1916.

GLASS-BLOWING, ETC.—A. Wilzin (*Pat. J.*, No. 1,431, 1916). Pat. No. 3,146, Feb. 26th, 1915. Relates to an automatic bottle-blowing machine, new features being combined with those described in Specification 20,299/13. A gathering device, and a cutting-blade for cutting off excess of metal, are included.

GLASS. GATHERING MOLTEN METAL.—A. Wilzin (*Pat. J.*, No. 1,433, 1916). Pat. No. 100,421, March 1st, 1916.

GLASS. LADLE.—A. Wilzin (*Pat. J.*, No. 1,435, 1916). Pat. No. 100,514, March 1st, 1916. Addition to Pat. No. 100,421, of same date.

GLASS-BLOWING.—A. Wilzin (*Pat. J.*, No. 1,477, 1917). Pat. No. 104,722, March 13th, 1916. The parison mould and gathering ladle of a glass-blowing machine are movable in paths at right angles to one another, and the parison mould and finishing mould are arranged in different horizontal planes. The neck mould is also movable vertically in relation to the parison and finishing moulds.

GLASS-GATHERING.—A. Wilzin (*Pat. J.*, No. 1,478, 1917). Pat. No. 104,989, March 13th, 1916. In a suction head for a glass-blowing machine, in which the molten glass is gathered by suction, the crosssectional area of the suction passage is automatically reduced towards the completion of the suction period as the molten glass rises in the parison mould towards the neck mould.

DELIVERING MOLTEN GLASS, ETC.—J. Connolly and J. A. Temple (*Pat. J.*, No. 1,477, 1917). Pat. No. 104,555, March 15th, 1916. In a glass-melting furnace provided with an enclosed side chamber, having at the bottom a discharge outlet, each gather issuing from the outlet is cut off by a pivoted plate, which is pierced by a slot with bevelled cutting-edges, so that each movement of the plate across the orifice first feeds and then cuts off a measure of molten glass.

DELIVERING MOLTEN GLASS.—Hartford-Fairmont Co. (*Pat. J.*, No. 1,477, 1917). Pat. No. 104,605, June 19th, 1916. A method of converging molten glass from the furnace to the shaping apparatus consists in causing the glass to flow, either as drops or as a continuous stream, along a conduit lined with a film of fluid.

FEEDING MOLTEN GLASS.—Hartford-Fairmont Co. (*Pat. J.*, No. 1,482, 1917). Pat. No. 105,672, June 19th, 1916. Relates to a method of feeding molten glass in gathers of uniform size and at uniform intervals, and consists in propagating in the glass tank timed waves or surges of the glass towards and over a dam.

DRAWING GLASS ROD AND TUBING, ETC.—General Electric Co. (*Pat. J.*, No. 1,480, 1917). Pat. No. 105,285, June 15th, 1916. Relates to developments of the machine described in Specification 17,602/13 for drawing glass rod and tubing, and comprises primarily a cooling-device which automatically follows the descending level of the molten glass during the drawing process.

CRUCIBLES.—J. Gray (*Pat. J.*, No. 1,487, 1917). Pat. No. 106,547, June 26th, 1916. Crucibles, particularly for use in gas manufacture, are made up of rods, bars, or slabs of tungsten, tantalum, nickel, fireclay, or other refractory material, held together by detachable bands.

GLASS-MELTING POTS.—G. M. Bowen (*Pat. J.*, No. 1,489, 1917). Pat. No. 106,871, June 13th, 1916. Glass-melting pots are built up, at a single operation, in burnt fireclay moulds formed of sectional rings which support and dry the walls of the pot. The top is formed upon an inflatable support which is withdrawn in a deflated condition after moulding, and may be provided with a blow-off valve to permit escape of air during contraction of the walls and top of the pot.

GLASS-MELTING POTS.—S. R. Scholes (*Pat. J.*, No. 1,450, 1916). Pat. No. 101,393, May 5th, 1916. A glass-melting pot or receptacle is formed of an outer body portion, of refractory material adapted to resist changes of temperature, and an inner lining of refractory material (integrally united with the body portion) adapted to resist corrosion by the action of the molten metal. Preferably, the body portion is made of a mixture of raw clay and burnt clay, with or without ground pot-shell, and the lining of a mixture of raw clay, burnt clay, and a vitrifying agent, such as felspar. The clay mixture ordinarily used in making glass-melting pots, and containing about one per cent. of an alkali vitrifying agent as an impurity, may be employed in making the outer body portion, and a refractory clay containing about two per cent. of alkali may be employed in making the lining.

GLASS MANUFACTURE.—H. J. F. Strandh (*Pat. J.*, No. 1,454, 1916). Pat. No. 101,685, June 29th, 1916. The batch mixture is divided into two portions, the first portion, which contains alkaline sulphates, silica and carbonaceous matter, being melted (to form alkaline silicate) before the second portion, containing say compounds of calcium and silica, is added. In a modified method the different portions of the batch may be placed in different layers or in different parts of the furnace and be heated all at one time. The least fusible constituents are preferably placed as a bottom layer to protect the furnace material, and the most easily fusible materials are placed near the furnace walls where the temperature is lowest. Calcium carbonate, arsenious acid, or other gas-producing substance may be added during the later stages of the melting to cause the mass to be stirred by the escaping gases.

CRUCIBLE FURNACES FOR GLASS, ETC.—C. F. Price (*Pat. J.*, No. 1,442, 1916). Pat. No. 100,849, Jan. 6th, 1916. A modification of the furnace described in Specification 17,574/15, by dividing the heating chamber into compartments closed by removable covers, and so arranged that any one or more of the compartments may be shut off from the producer.

GLASS FURNACES.—C. F. Price (*Pat. J.*, No. 1,475, 1917). Pat. No. 104,136, Oct. 17th, 1916. A modification of the same inventor's furnace described in Specification 100,849, Jan. 16th, 1916. The glass pots or crucibles are placed in a combustion chamber fixed above a sort of gas-producer, the sides of the latter being surrounded by flues which heat the air required for combustion, so as to give a more equal distribution.

FORMING ELECTRIC LAMP BULBS, ETC.—General Electric Co., Schenectady (*Pat. J.*, No. 1,452, 1917). Pat. No. 14,209, Oct. 7th, 1915. An automatic machine for blowing small electric lamp bulbs, etc., from glass tubing.

GLASS ELECTRIC LAMPS.—Morris and Whitham, and J. A. Allison (*Pat. J.*, No. 1,489, 1917. Pat. No. 106,892, July 12th, 1916. A machine for automatically flanging glass tubes for making electric lamps.

MOULDING GLASS, ETC., UNDER PRESSURE.—L. Grote and A. W. H. Vivian (*Pat. J.*, No. 1,490, 1917). Pat. No. 107,026, April 15th, 1916. In a moulding or pressing machine for manufacturing glass and other ware, a ring of pneumatically operated pressing plungers and a work table carrying the moulds rotate about a central pillar.

GLASS, ETC., FURNACES.—L. Grote and A. W. H. Vivian (*Pat. J.*, No. 1,491, 1917). Pat. No. 107,211, April 19th, 1916. In a furnace for melting glass and other materials the flames and hot gases from a plurality of burners are caused to take a whirling or cyclonic motion in superposed layers within the furnace.

GLASS-WARE BAKING-DISHES, ETC.—Corning Glass Works (*Pat. J.*, No. 1,439, 1916. Pat. No. 100,738, June 5th, 1916. Baking-dishes and other utensils subjected to great temperature changes are made of transparent glass. Compositions are given for sodium boro-silicate glasses suitable for such ware, the percentage of silica being not less than 70 per cent. of the total, and the percentage of boric oxide being not less than twice that of sodium oxide. Not more than 3 per cent. of alumina may be present The soda may be replaced by potash or lithia. Laboratory ware may be made thicker than usual, giving greater strength. These glasses have relatively high thermal conductivity and a relatively low coefficient of expansion. They also have a high thermal coefficient of endurance, and flow easily in the press at comparatively low temperatures.

GLASS-DRAWING.—Empire Machine Co. (*Pat. J.*, No. 1,493, 1917). Pat. No. 107,684, Aug. 10th, 1916. In order to equalize the temperature of the metal within the ring shield which surrounds the drawing aperture, a submerged diaphragm is arranged below the ring, and means are provided for adjusting the level of one part of the ring relative to that of another part. The shield may be tilted to any desired degree so that a greater depth of metal can be kept in one part of the ring than in another. The furnace is provided with a topstone over the drawing opening which is surrounded by a refractory shield dipping into the glass.

GLASS-DRAWING.—Empire Machine Co. (*Pat. J.*, No. 1,496, 1917). Pat. No. 108,217, Aug. 10th, 1916. The glass is drawn from within a ring, the lower edge of which is inclined so that the metal enters from different depths in the tank. By turning the ring so that its lowest point is in the hotter portions of the molten mass, it is possible to equalize the temperature of the glass within the ring.

"PRESSED-BLOWN" GLASS.—E. Riorant (*Pat. J.*, No. 1,497, 1917). Pats .Nos. 108,351 and 108,352, Aug. 1st, 1916. A machine in which only one set of moulds is used, but so arranged that the formation of a parison takes place simultaneously with the setting of the previous parison. The second specification has reference to moulds.

FIRE-FINISHING GLASS TUMBLERS, ETC.—H. H. Pitt (*Pat. J.*, No. 1,499, 1917). Pat. No. 108,713, Aug. 15th, 1916. Water, steam, air, or other cooling medium is passed through the stands whereon the tumblers (or other articles) are supported during the fire-finishing process. The machine is figured.

GLASS MANUFACTURE.—J. A. Chambers (*Pat. J.*, No. 1,472, 1917). Pat. No. 103,672, Jan. 26th, 1917. Relates to the production in connection with tank furnaces, of molten glass for use in drawing cylinders in making window glass, or for use incasting plate glass, the object being to eliminate bubbles from the glass.

DELIVERING MOLTEN GLASS.—O. M. Tucker and W. A. Reeves (*Pat. J.*, No. 1,482, 1917). Pat. No. 105,564, April 10th, 1917. Molten metal is allowed to extrude itself, through an aperture in a tank, etc., in the form of a gob or globule, which, when of the required size, is cut off.

SUBSTITUTE FOR GLASS.—(*Gas World*, 66, 335, 1917). It is pointed out that owing to the high temperature that fused silica withstands, it is possible to make all gas lighting cylinders and globes of fused silica much smaller than can be done with glass, thus enabling a high mantle temperature to be employed with corresponding increase of light. The want of quite complete transparency in the material rendered the light pleasanter to the eyes and gave a more equal diffusion. Fused silica is largely used for electric heating apparatus, and is very efficient for insulating purposes, as its insulating properties are retained at relatively high temperatures, and it is not hygroscopic in the same way as glass and china.

GRADUATIONS ON GLASSWARE.—C. Fiege, Ger. Pat. 295,552, May 5th, 1916. A burning-in process.

GLASS MIXTURE.—Macbeth, U.S. Pat. 1,214,202, Jan. 30th, 1917. To 1,500 parts of a foundation batch for clear glass are added 80 to 160 parts of alumina, 100 to 170 of fluorspar, and 100 to 200 of sodium silicofluoride. The fluorspar may be replaced by any other fluoride, and the silicofluoride by another fluoride.

ANNEALING LEER.—J. Plante, U.S. Pat. 1,214,217, Jan. 30th, 1917.

QUARTZ GLASS.—O. C. Trautmann, U.S. Pats. 1,215,432 and 1,215,433, Feb. 13th, 1917. Processes for producing tubes and moulded shapes of quartz glass, using electrical furnaces.

FUSING QUARTZ.—I. Rosenblum, U.S. Pat. 1,229,324, June 12th, 1917. The quartz is heated in a graphite crucible at 1,400°—1,700° C., in an atmosphere of nitrogen, the operation being conducted in an electric furnace. By the action of some of the quartz on the crucible lining a protecting layer is formed on the crucible. The temperature is afterwards raised to melt the quartz.

PLATE GLASS.—R. S. Pease, U.S. Pat. 1,217, 340, Feb. 27th, 1917. A process for refining glass contained in a tank.

POTS FOR MELTING PLATE GLASS.—C. H. Kerr, U.S. Pat. 1,217,956, March 6th, 1917. The pots are made of ordinary pot clay mixed with finely divided silica (or sand), the latter forming 8 to 30 per cent. of the mixture.

CLAY POTS OR CRUCIBLES.—H. K. Hitchcock, U.S. Pat. 1,221,450, April 3rd, 1917. A shaped, hollow, moist blank is enclosed within an air-tight impervious mould, so that its whole outer surface touches the mould, and the hollow inner surface of the blank is subjected to a partial vacuum to free it from air bubbles, occluded gas, and excess moisture. The whole inner surface of the blank is next subjected to uniform yielding pressure to make it equally compact throughout, and the blank is left under pressure until it becomes homogeneous.

COLOURING GLASSWARE.—H. Northwood, U.S. Pat. 1,217,490, Feb. 27th, 1917. The ware is stained with copper sulphate solution—with or without a binder (such as ferruginous clay)—then fired at about 480° C., cooled, and the binder (if present) removed. It is next coated with a solution of silver salt—with or without a binder—and again fired at about 480° C.

GLASS-MELTING POT.—E. A. Gillinder, U.S. Pat. 1,223,959, April 24th, 1917. The pot is closed at the top, except for a feed-inlet, and has a discharge passage in the lower part of its side leading to a well formed by an extension of the pot. The floor of the pot slopes towards the well.

GLASS INSULATOR.—F. M. Locke, U.S. Pat. 1,225,147, May 8th, 1917. A hest-resisting glass, with coefficient of expansion not exceeding 0·000005, is produced by melting together siliceous material (in relatively large amounts) with a boron compound, cryolite, and a little alkali.

REGENERATIVE GLASS FURNACE.—C. Menzel, Ger. Pat. 295,938, June 15th, 1916. Addition to Ger. Pat. 289,827. The roof of the furnace chamber has projecting ribs, so that the heating gases proceeding from the inlets on one side to the outlets on the other acquire a rotary movement which facilitates their action on the glass.

REVERSIBLE GLASS POT.—G. A. Shields, U.S. Pat. 1,226,022, May 15th, 1917. An integral reversible glass pot consists of two receptacles arranged base to base, and connected by a narrow neck in the middle, which forms an annular groove for an operating tool. A central boss projects from the bottom into each receptacle, and an air passage runs through both bosses and the connecting neck.

PATENT FOR MANUFACTURE OF ARTICLES PART GLASS AND PART PORCELAIN, BY USING A BOROSILICATE GLASS WITH SUITABLE COEFFICIENT OF EXPANSION.—F. Skaupy (*Deut. Top. Zieg. Zeits.*, 78, 25, 1915). H.E.W.

XI.—CEMENTS, MORTARS, CONCRETE, ETC.

ALKALIES FROM FELSPAR, ETC., CEMENTS.—H. E. Brown (*Pat. J.*, No. 1,429, 1916). Pat. No. 2,466, June 2nd, 1914. Alkaliferous materials, such as felspar, are fused with calcareous material, with or without additions such as calcium chloride or other cheap halogen salt, to render the alkali easily volatile; the residue after volatilization of the alkalies should contain 40 to 55 per cent. of lime. The operation is preferably conducted in a non-reducing or oxidizing atmosphere. The residue is available for producing hydraulic cement (as described in Specification 13,448/14, or may be suitably treated for the production of slag brick, glass wool, fillers for concretes, silicate roofing materials, etc. Specifications 26,497/12 and 28,970/12 are referred to.

PLASTIC COMPOSITIONS.—H. J. Guise and W. G. Perry (*Pat. J.*, No. 1,419, 1916). Pat. No. 23,345, Dec. 1st, 1914. A magnesia cement composition is made preferably by mixing 55 parts burnt magnesite, 15 burnt and ground china clay, 15 quartz, 10 asbestos, and 5 wood meal, the dry powder being mixed with magnesium chloride solution of 16—36° Bé, and then with paraffin oil. One gallon of magnesium chloride is used to one pint of paraffin oil. To the dry mix may be added respectively cork, powdered glass, slag, crushed sea-shells, and silicon carbide. The composition may be used as an adhesive cement. It may be employed for paving floors, decks, etc., for switchboards, partitions, electric insulators, etc., and for assembling porcelain insulators with metal parts, also for uniting porcelain, stone, metals, wood, glass, and leather.

QUICK-SETTING CEMENT.—Sir H. Denny and D. G. Anderson (*Pat. J.*, No. 1,415, 1916). Pat. No. 21,987, Nov. 4th, 1914. A quick-setting cement is produced by mixing substantially anhydrous gypsum with 1 to 10 per cent. of Portland cement.

CEMENTS.—L. P. Basset (*Pat. J.*, No. 1,417, 1916). Pat. No. 22,644, Nov. 17th, 1914. Addition to 17,873/13. Relates to modifications in the process described in the parent Specification for producing cement or hydraulic lime from calcium sulphate, clay, and charcoal.

SLABS.—N. Garnett (*Pat. J.*, No. 1,422, 1916). Pat. No. 24,667, Dec. 28th, 1914. Relates to slabs made of a specified composition, or of slate, cheap marble or granite, or Portland cement, etc., coated with the composition. The latter is made up of 40 per cent. ground calcined magnesite, 10 ground pumice stone, 5 gypsum, 3 sand, 2 colouring matter, and 40 magnesium chloride.

MORTAR; CEMENT.—A. Deckers (*Pat. J.*, No. 1,422, 1916). Pat. No. 24,761, Dec., 1914. A dry mortar or cement is made by grinding quicklime and granulous slag together. The lime is slaked by the "hydrate water" from the slag. Continued grinding produces a cement.

REFRACTORY SUBSTANCES; SLABS, ETC.—F. L. Schauermann (*Pat. J.*, No. 1,433, 1916). Pat. No. 4,142, March 16th, 1915. A mixture consisting preferably of 7 lb. silica, 4 oz. lime, 2·3 oz. sodium silicate, 1 oz. cuttle-fish powder, and 2·3 oz. water is moulded into firebrick or other refractory material, the moulded product being dried and burned. A mixture consisting preferably of 7 lb. sand, 4 oz. cement, 4 oz. sodium silicate, 1 oz. cuttle-fish powder, and 4 oz. water is used for moulding into bricks, building and paving slabs, and artificial stone.

ARTIFICIAL STONE.—A .Ford and P. Ford & Sons (*Pat. J.*, No. 1,433, 1916). Pat. No. 4,246, March 18th, 1915. Artificial stone resembling granite, etc., is made, for example, by mixing 60 parts of the crushed stone (with or without coarse siliceous sand) with a cement consisting of 30 parts of monohydrated or anhydrous calcium sulphate, and 5 to 8 parts of Portland cement, and 1 to 3 parts of aluminium sulphate. The mass is mixed with water and after setting may be treated with alkaline silicate to harden the surface. For polished stone, crushed alabaster or marble is used, together with the mixed cements, with water containing about 3 per cent. of alum or aluminium sulphate, and sometimes boracic acid. After setting, the stone is hardened with alkaline silicate and washed, and the surface is ground and polished.

COOLING CEMENT CLINKERS, ETC.—G. M. Park (*Pat. J.*, No. 1,442, 1916). Pat. No. 7,415, May 18th, 1915. Addition to 2,661/14. The first rotary chamber is modified so that the water used in cooling the clinker is recovered for boiler feed or other purposes.

SLOW-SETTING CEMENT.—J. Gresly (*Pat. J.*, No. 1,445, 1916). Pat. No. 8,551, June 9th, 1915. A slow-setting, white, hydraulic cement containing little or no alumina is made by adding calcium sulphate as the sole sintering-agent to a mixture of lime or calcium carbonate and quartz, or to calcium silicate or limestones containing silica, sintering, and grinding. For example, 34 parts calcium sulphate, 250 parts calcium carbonate, and 60 parts silica may be used.

ARTIFICIAL STONE.—K. Ogawa (*Pat. J.*, No. 1,459, 1916). Pat. No. 13,075, Sept. 13th, 1915. An artificial stone material is composed of incompletely burnt dolomite, mixed with magnesium chloride solution, and cork or sawdust, with a surface layer of similar material in which the filler is asbestos or slag wool. The composition is used for making decorative tiles, using pigments to give colour, and also for making pavements or for covering floors, walls, ceilings, etc.

SODIUM SULPHATE; CEMENT.—L. P. Basset (*Pat. J.*, No. 1,444, 1916). Pat. No. 8,128, June 1st, 1915. In the production of sodium sulphate and hydrochloric acid or chlorine by the Hargreaves process, the sodium chloride reacts in the form ofvapour or fine mist. If the sodium chloride be mixed with gypsum, clay, and coal, cement is also produced, the sodium sulphate being collected separately.

CEMENTS.—J. J. W. H. van der Toorn (*Pat. J.*, No. 1,459, 1916). Pat. No. 13,081, Sept. 13th, 1915. A mixture of titaniferous iron, sand and cement is used as a cement in building construction.

COLOURING, HARDENING, AND IMPREGNATING STONE, ETC.—L. A. Sanders and A. J. Sanders (*Pat. J.*, No. 1,459, 1916). Pat. No. 102,042, April 26th, 1915. Natural stone, bricks, cement, concrete, lime trass mortar, etc., are coloured, hardened, or impregnated so as to make them impervious to water, oil, acids, etc., by treatment, when sufficiently hardened, with a metal-salt solution or other metallic compound. The cement, etc., is mixed with water, metal-salt solution, or "other aqueous fluid," moulded or applied as a plaster, and after a time treated with copper, zinc, nickel, lead, iron, or other metallic sulphate, acetate, chromate, nitrate, chloride, etc. The plastering may be applied to stone, bricks, wood, cement-mortar, walls, floors, ceilings, roofs, sculpture, ornaments, tiles, slabs, etc.

MORTAR.—L. A. Sanders and A. J. Sanders (*Pat. J.*, No. 1,462, 1917). Pat. No. 14,226, Oct. 7th, 1915. A process for forming a metallic coating on cement-, gypsum-, trass-, or other mortar comprises mixing the cementitious material with finely-divided metal or ore, or both, and a liquid so as to form a mortar, and afterwards treating the surface of the hardened mortar with a solution of a salt, such as copper sulphate, whereby the metal of the salt is precipitated on the surface, or the metal in the mortar is replaced to a certain depth by the metal of the salt.

ANNEALING SLAG BRICKS, ETC.—T. W. Ridley (*Pat. J.*, No. 1,474, 1917). Pat. No. 17,955, Dec. 23rd, 1915. Kilns for annealing slag bricks or blocks are made with their length greater than their width, and the latter decreases towards either or both ends. The sides may be straight or slightly curved, so long as either or both ends are semicircular, oval, triangular, or polygonal.

CONCRETES.—E. O. C. Howells (*Pat. J.*, No. 1,478, 1917). Pat. No. 105,054, March 23rd, 1916. Nos. 2,401/17 and 6,428/16 are mentioned. A mixture of 1 part of cement with 6 parts of breeze, or with 5½ parts of breeze and ½ part of granite dust, is used for making slabs and other building-units.

SHAFT FURNACES OR KILNS.—Beocsini Cementgyàri Unio Részvenytarsacág V. (*Pat. J.*, No. 1,491, 1917). Pat. No. 107,209, April 6th, 1916. A furnace or kiln for roasting material capable of fritting such as Portland cement or magnesite is provided with a grate movable as a whole and having toothed or corrugated crushing bars arranged to form a substantially flat surface with spaces for the passage of the broken material.

CEMENTS.—T. Moniwa (*Pat. J.*, No. 1,493, 1917). Pat. No. 107,613, June 1st, 1916. Glazed tiles or like smooth and non-absorbent surfaces are cemented together or to other substances by means of a mixture of asphalt (or the principal ingredients thereof, namely, bitument and asphaltine) and non-melting mineral matter, such as powdered quartz and asbestos.

TREATING SLURRY.—C. Pontoppidan (*Pat. J.*, No. 1,452, 1916). Pat. No. 101,484, Sept. 15th, 1916. Slurry for making Portland cement and for other purposes is made more fluid, and its water content can therefore be reduced by the addition of chemical reagents, such as electrolytes. As examples, sodium or potassium carbonate or hydrate, sodium chloride, and potassium sulphate or nitrate are mentioned, and percentages varying from 0·05 of sodium carbonate to 0·6.

ARTIFICIAL STONE.—E. O. C. Howells (*Pat. J.*, No. 1,477, 1917). Pat. No. 104,595, March 23rd, 1916. A mixture of about 4 parts of granite, and 1 part of Portland cement, to which is added about 10 per cent. of Bessemer steel slag, is used for making artificial stone.

REINFORCED CONCRETE.—F. Cook (*Pat. J.*, No. 1,494, 1917). Pat. No. 107,868, Sept. 5th, 1916. Concrete, consisting preferably of 1 part of cement and 5 parts of flying ashes as described in Specification 23,541/12, is strengthened by the insertion during moulding of longitudinally-arranged flat strips of metal in one or more horizontal layers.

CEMENTS, CONCRETES, AND MORTARS.—Z. Morikami (*Pat. J.*, No. 1,442, 1916). Pat. No. 100,886, June 27th, 1916. A powder for mixing with cement, concrete, and mortar to make them water-tight consists of a mixture of calcium soap (100 parts) and powdered burnt alum (10 parts).

PLASTIC COMPOSITIONS.—J. C. G. Sperni and L. S. Burt (*Pat. J.*, No. 1,473, 1917). Pat. No. 103,775, Aug. 2nd, 1916. A mixture of (for example) 50 parts of sawdust and 25 parts each of burnt magnesite and pumice is treated with sufficient magnesium chloride solution of 18—25° Bé. to produce a semi-dry mass, which may be moulded into slabs and the like, or may be used for roofing, partitions, wall coverings, floors, etc. The composition may be reinforced and may be coloured.

ALKALI CARBONATES AND CEMENT.—E. W. Jungner (*Pat. J.*, No. 1,470, 1917). Pat. No. 103,290, Dec. 8th, 1916. Relates to a process for preparing alkali carbonates, in which Portland cement also may be obtained if desired, by heating an intimate mixture of a powdered alkaliferous mineral silicate such as felspar, or alkaliferous clays or slate, a calcareous material, and finely-divided carbon or carbonaceous matter in an atmosphere containing CO_2. If Portland cement is to be produced simultaneously with the alkali, the percentage of lime should be such as to produce a hydraulic modulus (that is, molecular ratio of lime to sum of silica, alumina, and ferric oxide) of at least 1·7, and preferably 2·1. The amount of carbon used is 4—10 per cent. of the weight of the raw mixture. If a large quantity of free silica is present in the raw materials, small quantities of iron oxides (for example, iron ore) or substances containing a large percentage of alumina (for example, bauxite) are added. A temperature of 1,250—1,400° C. is required, and whether or not cement is desired as a product, the operation is preferably conducted in a cement furnace. If a shaft furnace is employed, the mixture is briquetted, for example, by moistening with slaked lime which has been puddled in water; and if the furnace is an electric one it is necessary to supply CO_2, or air if the amount of carbon in the charge is sufficient. Specifications 26,497/12 and 28,970/12 are referred to.

ARTIFICIAL STONE.—E. Imer-Schneider (*Pat. J.*, No. 1,475, 1917). Pat. No. 104,154, Feb. 5th, 1917. A mixture of cement, asbestos, and vegetable fibre, such as sulphite wood pulp or cotton, which has been previously treated with a cold solution of alkali, is used for making slabs, etc. In an example, the mixture consists of 100 parts cement, 300—600 parts water, 1—3 parts asbestos, and 2—3 parts vegetable fibres.

MIXING MACHINES.—Ransome Concrete Machinery Co. (*Pat. J.*, No. 1,493, 1917). Pat. No. 107,575, March 28th, 1917. A rotary drum for mixing concrete, etc., is fitted with lifting-blades and with blades spaced from the inner walls of the drum and disposed substantially flatways for receiving and deflecting laterally the materials falling from the lifting-blades.

CEMENTS.—T. D. Kelly (*Pat. J.*, No. 1,494, 1917). Pat. No. 107,951, April 21st, 1917. Hydrated Portland cement, preferably 100—300 parts, is mixed with 5—30 parts of water-glass and 5—10 parts of an adhesive liquid, insoluble in water and not readily saponifiable, such as oxidized or polymerized oil, with or without a filler. Heat accelerates setting.

CEMENTS.—Electro-Chemical Supply & Engineering Co. (*Pat. J.*, No. 1,496, 1917). Patent No. 108,278, March 26th, 1917. Siliceous matter, such as quartz, is mixed with apatite or calcium phosphate and sodium silicate, all preferably in a dry state, to produce an acid-proof cement which may be moulded. In order to use it, it is moistened in the usual way and either before or after it sets it is treated with sulphuric or other acid which renders the product waterproof. Suitable proportions are 90 parts siliceous matter, 10 parts phosphate, 30 parts sodium silicate.

SEPARATING ALKALI-METAL COMPOUNDS; CEMENT.—W. A. Schmidt (*Pat. J.*, No. 1,501, 1917). Pat. No. 109,105, Sept. 5th, 1916. Potassium and other alkali-metal compounds are separated from mineral silicates, such as felspar, or from other potash-bearing substances, by roasting in presence of lime or other alkaline earth, and preferably also in presence of sulphur dioxide and oxygen, and cooling the fume to obtain the volatile potassium or other compounds as condensed particles, which are separated in an electric separator. The process may be used in connexion with the manufacture of cement, using a mixture of clay, lime, etc., and employing the arrangements of which a figure is given.

BUILDING MATERIAL.—T. Gürtler, Ger. Pat. 295,013, April 7th, 1914. Burnt clay, kaolin, or other material containing alumina and silica, is mixed with a calcareous binding medium, and hardened by treatment with steam under pressure.

PORTLAND CEMENT AND SIMILAR PRODUCTS.—W. H. Mason, U.S. Pat. 1,210,510, Jan. 2nd, 1917. An unground mixture of cement-forming materials is calcined in one section of a rotary kiln, then passed through a grinding section, and then through a second burning section where it is converted into clinker. Each section can be rotated separately, but the three sections are in a straight line and have a continuous closed passage through them.

DUST FROM WASTE GASES OF CEMENT KILNS.—G. Polysius, Ger. Pat. 295,490, Jan. 25th, 1916. The gases are washed by passing them through the slurry tanks, wherein they are much better cleaned than in ordinary wet scrubbers.

CEMENT AND BY-PRODUCTS FROM FELSPAR, ETC.—E. C. Eckel and A. C. Spencer, U.S. Pat. 1,209,135, 1,209,219, and 1,209,220, Dec. 19th, 1916. Cement is made by heating a finely ground mixture of potash felspar, glauconite, or nephelite or potash mica, with limestone or other calcareous material, the temperature being sufficient to volatilize the potash and form cement clinker, but without fusion. The potash is recovered from the flue-dust.

ROTARY CEMENT KILN GASES.—L. Stevens, U.S. Pat. 1,214,725, Feb. 6th, 1917. The flue gases are cooled by water (converted into steam) and then passed through a dust separator in which the dry suspended matter collects. The quantity of water mixed with the gases is regulated automatically according to the temperature.

PRODUCING CEMENT AND RECOVERING POTASSIUM COMPOUNDS.—F. W. Huber and F. F. Reath, U.S. Pat. 1,219,315, March 13th, 1917. The flue-dust from cement kilns is mixed with an alkaline earth halide (*e.g.*, calcium fluoride) and strongly heated so as to liberate and volatilize the alkalies, the product (in the form of flue-dust) being collected and mixed with calcium fluoride, then digested with water to extract the potash.

WATER-PROOF CEMENT.—H. Kunze and others, Ger. Pat. 296,537, April 30th, 1914. Hot cement clinker is mixed with an easily melting solid like paraffin, which owing to its low viscosity fills up the pores. The grinding mills are fed with a mixture of porous and saturated clinker.

LEACHING FLUE-DUST FROM CEMENT KILNS.—F. W. Huber and F. F. Reath, U.S. Pat. 1,220,989, March 27th, 1917.

WATER- AND ACID-PROOF CEMENT.—U. Wedge, U.S. Pat. 1,220,575, March 27th, 1917. Siliceous material is mixed with an acid and afterwards with sodium silicate. The finely divided silica, which is precipitated, makes the cement water-proof and acid-proof.

REFRACTORY CEMENT.—F. W. Sperr, jun., and R. J. Montgomery, U.S. Pat. 1,221,618, April 3rd, 1917. The cement mixture consists of about 25 fireclay, 35 silica, 35 silica bats, and 5 felspar.

MIXING MORTAR.—E. Becker, U.S. Pat. 1,223,239, April 17th, 1917. Mortar—consisting of lime or cement, water, and sand—is preserved by the addition, during the mixing, of lead acetate to the amount of more than 0·5 per cent. of the lime or cement. Insoluble lead salts are produced with substances which might otherwise injuriously affect the mortar.

ARTIFICIAL STONE SLABS, ETC.—W. Sänger, U.S. Pat. 1,223,834, April 24th, 1917. Artificial stone slabs, shingles, plates, etc., are made from a mixture of hydraulic cement, fine asbestos fibre, precipitated anhydrous silica, and water, the latter being about twice the weight of the dry materials. The surface of the slabs may be hydrated by steaming, and the whole is hardened and made stronger by the formation of insoluble silicates as the result of exposure to atmospheric carbon dioxide and moisture.

WHITE HYDRAULIC CEMENT AND POTASH SALTS.—C. Ellis, U.S. Pat. 1,224,454, May 1st, 1917. A mixture of a mineral silicate containing potassium with a calcareous material is heated to a temperature below that at which the potassium compounds volatilize, the heated mixture being then quenched in calcium chloride solution. The product in a state of sub-division is quickly heated to a clinkering temperature, forming a cement clinker, whilst the potassium salt is volatilized and is separated from the waste gases.

MIXING CEMENT-MORTAR AND CONCRETE.—M. T. Hockstrasser, U.S. Pat. 1,225,129, May 8th, 1917. Finely ground cement is sifted into excess of water to form a colloidal body. After draining off the excess of water the residue is mixed with the coarser ingredients of the concrete or mortar.

XII.—ANALYTICAL PROCESSES.

DETERMINATION OF BORIC ACID IN SPECIAL GLASSES.—P. Nicolardet and J. Boudet (*Bull. Soc. Chim.*, 21, 97, 1917). A modification of the method sometimes ascribed to Hönig and Spitz, though described by Klein many years earlier. One grm. of the powdered glass is gently fused in a platinum crucible with 5 grms. of mixed alkali carbonates, the product being disintegrated with hot water, and boiled for 5 minutes with 5 grms. ammonium chloride. The silica is precipitated by passing a current of carbon dioxide for 10 minutes, the liquid being then boiled to drive off ammonia, and allowed to stand. The precipitate contains the silica and all the metallic oxides (those of zinc, magnesium, calcium, and aluminium), the boric acid remaining in solution. The precipitate is washed with water containing a little ammonium chloride, and to the filtrate and washings is added 5 grms. pure sodium hydroxide, the mixture being heated to remove ammonium salts, and evaporated to 100 c.c. The liquid is transferred to a half litre flask, neutralised with hydrochloric acid (using methyl orange as indicator), and then boiled for 15 minutes beneath a reflex condenser to remove carbon dioxide. When cool, one drop of methyl orange solution is added, the liquid is titrated with deci-normal sodium hydroxide solution (free from carbon dioxide) until yellow again, then 10 c.c. of glycerol, or of freshly prepared solution of mannitol

(0·8 grm.) in boiling water, is added, and the titration completed with phenolphthalein as indicator. The presence of magnesia or alumina does not interfere with the determination of boric acid by this method, nor by the method of distilling it as methyl borate.

COLORIMETRIC DETERMINATION OF ORGANIC IMPURITIES IN SANDS.—D. A. Abrams and O. E. Harder (*Chem. Engineer*, 25, 9, 1917; *Analyst*, 42, 217, 1917). 200 grms. of the dry sand is digested for 24 hours (with occasional stirring) with 100 c.c. of 3 per cent. sodium hydroxide solution and the extract filtered. 10 c.c. of the clear filtrate is made up to 50 c.c. with water, and the colour compared in Nessler cylinders with that of freshly made sodium tannate solution (10 c.c. of a 2 per cent. solution of tannic acid in 10 per cent. alcohol, mixed with 90 cc. of 3 per cent. sodium hydroxide solution, and liquid left to stand 24 hours). From 1 to 10 c.c. of this solution is made up to 50 c.c. with water for the comparison, and the colour value in parts of tannic acid per million of the sand is 100 times the number of c.c. of the sodium tannate solution required to match the colour. This test has proved that there is a relationship between the amount of organic impurities and the colour values, and that sands with high colour values give low results in mortar tests. A colour value of 250 corresponded to a loss of 10 to 20 per cent. compressive strength in a 1 : 3 mortar; a value of 500 to a loss of 15 to 30 per cent.; 1,000 to a loss of 20 to 40 per cent.; 2,000 to 25 to 50 per cent. loss; and 3,000 to 30 to 60 per cent. loss.

Reviews.

Refractory Materials: Their Manufacture and Uses, by Alfred B. Searle.

(London: Charles Griffin & Company, Ltd., 1917. Price, 15/- net).

IT may be stated at once that this book presents a large amount of valuable information gathered from various sources, and it appears to include references to nearly all the most important points in recent developments. The range of products dealt with is unusually wide, including bricks (and in some cases shaped blocks, slabs, etc.) made from fire-clay, basic materials, bauxite, coke and other forms of carbon, chromite, silicon carbides and carboxides; saggars, muffles, crucibles, glass-pots, retorts; fused silica ware, refractory porcelain, refractory mortars and cements. The last chapter treats of the selection and application of refractory materials, and is followed by an appendix which comprises certain standard specifications, etc., with finally a general index. Manufacturing processes are described, often in considerable detail, sometimes more briefly, with the aid of numerous illustrations of objects, machinery, kilns, operations, distributed through the book, besides various diagrams, tables, etc.

But while the conception of the work and its general character is highly commendable, there are certain features open to criticism or improvement. One reflection which occurred repeatedly to the reviewer in looking through the book was as to why such works as this cannot be sent out free (or practically so) from misprints. It is by no means impossible to eliminate serious misprints and mis-statements, and as they are liable to be very troublesome, special efforts ought surely to be made to ensure substantial accuracy. A glaring instance occurs on p. 4, where formulæ of a series of alumino-silicic acids are ascribed to Dr. Mellor, which it is safe to assert that gentleman would not acknowledge as having been suggested by him. As a matter of fact, the six formulæ as printed are practically identical. It may be well to point out that the x and y should be omitted throughout, and the numbers 2, 3, 4, 5, 6 should only appear in conjunction with the SiO_2; it would also be preferable to substitute n for z, as in the

original. This in itself may be only a small matter, but writers on technical subjects being usually regarded as more or less infallible authorities, it behoves them to do everything in their power to avoid weakening that impression. In general, it may fairly be said that the author of the book under review is less happy in his treatment of theoretical or speculative matters than in his descriuptions of appliances and processes. The formula assigned to alumina on p. 5 is manifestly incorrect, though it might puzzle students. It should not be assumed that the hexite-pentite theory as applied to the structure of clay molecules is universally or even widely accepted, but of course there can be no valid objection to its introduction here providing it is properly explained. The symbolical representations at the bottom of p. 6, and those on pp. 7 and 8, will scarcely convey any clear meaning to students or general readers of average intelligence who may try to understand them, but in this case they are referred to another book for fuller information.

As ammonium salts, when present, are volatilized on heating clay, it is not easy to see how they can increase the fusibility of a clay even slightly, as is suggested on p. 51. On pp. 122 and 123 ytterbia is printed instead of yttria. Occasionally loose expressions occur, as on p. 264, where reference is made to "the space between each brick"; another instance is on p. 373, "when the proportion of alumina is high, and that of the *felspar or other base* low," the words italicised being in this connection unsupported by authoritative usage. It looks like a bad misprint on p. 284, where, referring to proportions for saggars, it is stated that "it is not usual to have more than 1 part of grog to 8 parts of fireclay"; even the substitution of 3 for 8 would not make it correct. Another remarkable statement appears on p. 341, in reference to glass-pots, after running casting slip into the mould. "The latter is then taken on the waggon to the drying room, where it is allowed to stand for twenty-four hours, after which any superfluous fluid is run off and the core removed." Speculation naturally arises as to uniformity of thickness after such treatment.

With reference to Wernicke's investigations mentioned on pp. 96 and 97, though the results seem conclusive for the quartzites examined it would be well to bear in mind that (according to McDowell) microscopical examinations of the best American quartzites—which are said to have no cementing ground mass, but to consist of interlocking quartz crystals—do not support Wernicke's views. The statement near bottom of p. 96 must surely be based on a misapprehension. Which

of the silica rocks used in the British Isles or in America contain any amount of tridymite?

Where the results obtained by other investigators are alluded to, the value of the book would have been considerably enhanced by giving full references in all cases.

The volume is issued opportunely, when the refractory materials interests, roused by the necessities arising from war conditions, are displaying extraordinary activity, and a comprehensive summary of the state of knowledge in that sphere can be of extensive use, notwithstanding such defects as those alluded to, which, though far from exhausting the list, include (it is hoped) the worst examples.

Notes on the Manufacture of Earthenware, by E. A. Sandeman.

(London: Crosby Lockwood & Son, 1917. Price, 7/6).

The demand for a second impression of this work may be taken as sufficient evidence that its value is appreciated. There is no material alteration in the re-issue. Even mistakes are perpetuated, such as the mis-spelling of Seger's name, which appears as Segar on pages xii and 230. Indeed, the only rearrangements noticed are a few substitutions—of *z* for *s*, small letters for capitals in some compound words, and italics for ordinary type, all these being mostly (if not entirely) in the preface and contents—with a liberal addition to the number of paragraphs in the text resulting from breaking up single paragraphs in two or more. This latter point will no doubt be welcomed by most readers, as many paragraphs in the original issue were of inordinate length.

It is to be regretted that, as stated in a note, the author had "neither the time nor the inclination to undertake the task of revision," for though the work, generally speaking, had been so well executed that probably little actual revision was necessary, it would have been very acceptable if notices of recent developments, such for example as those connected with casting, could have been included. Moreover, the author might perhaps have seen reason to modify several of the opinions so freely expressed on various aspects of the subject, and which for the most part are sound enough. Deficiencies notwithstanding, the book retains its position as the best in its particular field.

Possibly in the event of further issues the publishers might be able to arrange somehow to provide a general index, which would greatly increase the usefulness of the work for ready reference.

Glass and Glass Manufacture, by Percival Marson.

(London : Sir Isaac Pitman & Sons, Ltd. Price, 2/- net).

This little book is one of a series dealing with Common Commodities and Industries, and is evidently written by one who is well acquainted with his subject. It presents in a handy form a comprehensive though brief account of the many interesting processes involved in the production of the different kinds of glass, with as a rule sufficient illustrations and details to make the descriptions intelligible even to those who have no personal knowledge of the interior of a glass works. The index at the end should prove useful for ready reference to particular topics.

Misprints are not very numerous, and usually not seriously misleading, but several statements have been allowed to pass which are decidedly open to question. Thus on p. 4 it seems to be implied that lead oxide is to be reckoned among the alkalies. In the list of chemical formulæ (not formula as in the heading) on p. 14 nickel oxide is represented as NiO_2, "nitre" as$NaNO_3$, and sodium fluoride as NaF_2, while "barytes" is used on p. 8 and p. 26 as equivalent to "barium." These are comparatively small points, and doubtless are due to inadvertence, but the author will see the advisability of correcting them in any re-issue. On p. 111, in connection with four wheels, there is an awkward-looking reference to "The first," . . . . "the two second," . . . . "and the third."

The appendix, giving journals and books for reference, is good as far as it goes, but could easily be considerably extended if necessary; it is marred by one or two misprints, notably, "*Spreechall*" for "*Sprechsaal*."

Abstracts.

I.—RAW MATERIALS.

THE ADVANTAGES OF CLAY STORAGE.—F. H. Riddle (*Trans. Amer. Cer. Soc.*, 19, 102, 1917). The author concludes that in many cases the extra cost of storage is more than compensated by the advantages (especially when the storage is accompanied by weathering) resulting from greater uniformity of the material, reduced losses in firing, etc. An illustrated description is given of a successful installation for the purpose.

Weathering can be accomplished very well with the clay covered, where steam pipes are used beneath.

A PECULIAR TYPE OF CLAY.—H. Ries (*Amer. J. Science*, 44, 316, 1917). Refers to a clay from W. Texas, which appeared to be a gritty clay resembling loess. On mixing with water it readily made bricklets, and these fired at 950° C. gave a moderately hard porous body, which on exposure to moisture disintegrated completely. On microscopic examination the material was found to consist almost entirely of small rhombs, averaging about 0·008mm. across. The quantity of very fine indeterminable clay particles was practically negligible. Chemical analysis showed it to contain 98½ per cent. dolomite and 1½ per cent. iron oxide and alumina. Being an earthy material possessing distinct plasticity when wet, it is physically a clay.

Most clays under the microscope show a variable number of irregular grains (some siliceous), as well as numerous very small particles, which may be bunched together, and are in part colloidal.

Plasticity in clays seems to be due to the existence of gelatinous or colloidal matter, organic or inorganic, but the effect of these materials may be modified by absorbed salts, the relative proportions of large and small grains, and perhaps by the size of the grains. This view no doubt applies to most clays, but in the present case, even if all the iron oxide and alumina be assumed to be in the colloidal state, the total amount of colloidal material is not more than 1½ per cent. While this small amount of gelatinous material may serve as a contributory cause, it would seem that the very numerous small dolomite rhombs must be in contact by many of their flat faces, or separated by a thin film of water when the clay is wet. The surface tension would tend to hold the surface of the grains together, but would not prevent them slipping under pressure, thus giving mobility to the mass, and increasing its plasticity. Wheeler states that calcite finely ground in a ball mill developed plasticity, and the plasticity of this very abnormal clay may be mainly of the same nature.

THE MARLS AND CLAYS OF NORTH STAFFORDSHIRE.—J. T. Stobbs (Trans., 16, 107, 1917). An illustrated general account of the argillaceous deposits of the district.

FIRECLAY FROM A MANUFACTURER'S POINT OF VIEW.—G. H. Timmis (Trans., 16, 197, 1917). An account of the mode of occurrence, properties, and manner of getting fireclay, with special reference to the Stourbridge raw material. Reference is also made to testing, with a passing allusion to German products.

THE CLAYS OF SOUTH STAFFORDSHIRE AND ITS BORDERS.—W. S. Boulton (Trans., 16, 237, 1917). A comprehensive illustrated account of the local clays, with special and detailed reference to the clays of the Stourbridge district. Some remarks on the origin of fireclays are included.

VALUABLE FIRECLAYS AND GANISTERS OF THE SOUTH OF SCOTLAND.—L. W. Hinxman and M. MacGregor (Trans., 17, 35, 1918). A comprehensive survey of the subject.

MILLING OF POTTING MATERIALS.—H. J. Plant (Trans., 17, 123, 1918). An account of the preparation and grinding of flints, stone, felspar and bone, with the grinding of glaze, etc. Cylinder grinding and pan grinding are compared.

ASBESTOS.—(*Bull. Imp. Inst.*, 15, 287, 1917). Abstract of paper by R. P. D. Graham in *Economic Geology* (12, 154, 1917) dealing with the origin of the massive serpentine and chrysotile asbestos in the Black Lake—Thetford area of Quebec. The formation of joint planes in the peridotite masses, and the serpentinisation of the rock, are supposed to have taken place more or less contemporaneously with granitic intrusions, the change to chrysotile being brought about by uprising siliceous water dissolving material and afterwards depositing it as fibrous crystals.

FIRECLAY IN SOUTH AFRICA.—(*Bull. Imp. Inst.*, 15, 288, 1917). Abstract of paper by P. A. Wagner in *Trans. Geol. Soc. South Africa* (19, 36, 1916) dealing with clays used for making firebricks and earthenware. Several analyses are given. Most of them are rich in alumina, resembling china clay or ball clay. A sandy variety closely resembles Stourbridge fireclay.

MAGNESITE IN AUSTRALIA.—(*Bull. Imp. Inst.*, 15, 291, 1917). Abstract of F. R. Feldtmann's account of the magnesite deposit at Bulong (about 20 miles east of Kalgoorlie) in the *Rep. Dept. Mines, Western Australia*, 1915. The magnesite occurs chiefly as short irregular veins in serpentine rock.

MAGNESITE IN CANADA.—M. E. Wilson (*Trans. Amer. Cer. Soc.*, 19, 254, 1917). An account of the magnesite deposits of the Grenville district, Quebec. The magnesite is associated with dolomite (intimately) and serpentine, with smaller quantities of diopside, talc, phlogopite, quartz and other minerals. In the same vicinity occurs a sillimanite-garnet gneiss, probably the result of metamorphism of shale. The magnesite deposits probably originated in a manner very similar to the Austro-Hungarian deposits, by replacement of crystalline limestone through the agency of solutions emanating from pyroxenic igneous intrusions. Considerable masses of the magnesite have a lime content of 3 to 12 per cent. Only these portions are worked at present, the product averaging 6 to 10 per cent. of lime.

APATITE: A SUBSTITUTE FOR BONE ASH IN BONE CHINA.—(Summary Report of Mines Branch of Department of Mines, Ottawa, 108, 1916). An account of Canadian deposits of apatite, north of Ottawa. This apatite is usually pale green, and either massive or granular (sugar apatite). It occurs in large masses in pyroxenite rock, the associated minerals being mica, felspar, pyroxene, and a very small amount of pyrite. In five samples from different mines the lime ranged from 53·30 to 55·70, the P_2O_5 from 37·50 to 40·15, the alumina and Fe_2O_3 from 0·72 to 1·30 in four samples, and 8·72 in the fifth, the fluorine from 3·05 to 3·30, alkalies less than 1, with still less magnesia, water and chlorine. Trials of apatite china bodies fired at cones 8 and 9 showed promising results.

APATITE, A SUBSTITUTE FOR BONE ASH.—N. B. Davis (*Trans. Amer. Cer. Soc.*, 19, 125, 1917). A preliminary to an extensive investigation. The possibility of using Canadian apatite, instead of bone ash, for making bone china is suggested.

REFRACTORY MATERIALS IN CANADA.—(Summary Report of Mines Branch of Department of Mines, Ottawa, 111, 1916). A brief account of the distribution of the raw materials for refractories, including clays and shales, chromite (found in parts of Quebec province and British Columbia), quartzites and sandstones, and magnesite (the production of which in the Grenville district has increased from 120 tons in 1908 to about 55,000 tons in 1916).

MAGNESITE IN SOUTHERN NEVADA.—(*U.S. Geol. Survey Press Bulletin*, No. 259, February, 1916). An immense deposit of magnesite had for some time been mistaken for porcelain clay (kaolin), and forms part of a regularly stratified series of sedimentary deposits. It is chalky-looking, porcelain-white, fine-grained, and massive, very free from foreign material, but not so hard as the more typical magnesite.

II.—THE PHYSICAL, CHEMICAL, AND OTHER PROPERTIES OF RAW AND FINISHED PRODUCTS. TESTING.

CONSTITUTION OF DINAS BRICKS.—Dr. Endell (*Bericht* 32, *ordentliche Hauptversammlung des Vereins deutscher Fabriken feuerfester Produkte, E.V.*, 1912, p. 68). The temperatures to be resisted in the crown of Siemens-Martin furnaces vary between 1,650 and 1,750° C., and in particular cases 1,800° C. and even higher, and Dinas bricks are often exposed six months or longer to these high temperatures. One feature which sometimes makes itself unpleasantly noticeable is the permanent expansion of the Dinas bricks in the furnace, and to avoid this as far as practicable the bricks are, previous to using in the furnace, exposed to the highest possible temperatures (about 1,450° C.). In some places Dinas bricks which have been a very long time in use again showed a slight contraction. In 1884 H. W. Cronquist suggested expanding liquid inclusions in the quartz as the cause of the expansion of the Dinas bricks, but this alone was insufficient to explain the facts. In 1890 E. Mallard found tridymite crystals formed in quartz bricks after prolonged heating. The change from quartz into tridymite, taking place at about 1,000° C., corresponds to a volume expansion of 14·2 per cent. This observation of Mallard seems to have been entirely forgotten. E. Cramer's researches (1901) indicated that the volume increase of quartzite brick substance amounted on an average to 16 to 17 per cent. But this value is frequently not reached, and sometimes with repeated burning a slight contraction takes place. The cause was sought in the foreign admixtures of the always somewhat contaminated quartzite, which bring about a vitrification. These trials were not tested microscopically. Yet the opinion was always expressed that the quartz could have changed into the amorphous modification. This ought to be confirmed later.

Very recently two investigators have examined microscopically the changes of Dinas bricks in the burning, Grum-Grzimailo (1911) and Sokolow (1910), who again discovered tridymite in Dinas bricks which had been a long time in use. In order to avoid the injurious expansion of the bricks in the furnace, the proposal is made to accomplish the change from quartz into tridymite in the burning. Impure quartzites are therefore better for the manufacture of Dinas bricks, because through their impurities they offer more centres of change than milky pure vein-quartz. The purer the quartz the higher must the temperature be, and the longer must it be burned.

P. J. Holmquist (1911) pointed out that in many Dinas bricks the quartz grains are partly amorphous. By close examination in the polarizing microscope Cramer's supposition could be confirmed. Holmquist also observed the characteristically twinned tridymite crystals. In such quartz bricks, which in the very great heat were melted to stalactites, which hung from the roof of the furnace, he discovered cristobalite, the third known modification of quartz, though he did not establish its identity.

The change from α- into β-quartz at 575° C. is connected with no measurable change of volume. At about 1,000° C. quartz is very slowly changed into tridymite, the specific gravity changing from 2·65 to 2·32, the increase of volume being 14·2 per cent.; after cooling the tridymite remains. (Pure rock crystal, in pieces of about the size of hazel nuts, after firing twice in the porcelain oven—at about 1,450° C.—showed no change.) The cone melting

point of quartz (or tridymite or cristobalite) is usually taken as cone 36. J. Joly puts it at 1,425° (about cone 14—15).

In viscous materials like silicates and quartz two points must be distinguished:—

1. Change from the crystallized into the amorphous isotropic condition. It is essential to point out that in this change of condition the viscosity need not be changed.

2. The liquefaction occurring at higher temperature, the determination of which remains left entirely to the subjective opinion of the observer.

The volume change in the transition into amorphous "solid glass," as it may be termed for short, is the same as in liquefaction; this has been established by numerous measurements on various silicates. Since the commencement of the quite gradual liquefaction, with rising temperature, of a silicate or of quartz cannot be measured accurately, the temperature corresponding to the change from the crystallized into the amorphous isotropic condition is termed the melting temperature of the substance. The melting temperature of felspar (microcline with albite) was accordingly found at 1,160° C. (cone 2—3), that of quartz at about 1,450° to 1,470° C. (cone 15—16). The determination of the melting temperature is made by the so-called difference method. The specific gravity, index of refraction and double refraction were determined of powdered crystals which were exposed for a long time to various high temperatures and then quickly cooled. Since the phases stable at high temperature are after rapid cooling also capable of existence at room temperature, the different determinations can be undertaken without prejudice at room temperature. A sudden transition in the specific gravity (index of refraction, double refraction) temperature curve corresponds to the melting temperature.

Rock crystal (99·7 per cent. SiO_2) in very fine powder was electrically heated for four hours at 1,470°C., and the specific gravity and index of refraction of the partly isotropic and amorphous quartz glass was taken. Milky-white Norwegian vein-quartz (99·9 per cent. SiO_2), flint (98·7 per cent. SiO_2), and even quartzite (96 to 98 per cent. SiO_2) were by four hours heating at 1,420—1,430° C. (cone 14) converted into the isotropic amorphous state. The amorphous "solid quartz-glass," which still possesses completely sharp edges and angles, has not changed its viscosity in relation to that of the crystal. It softens quite gradually only at substantially higher temperatures, being first noticeable at temperatures above 1,600° C. One point (selected in somewhat arbitrary manner) of this softening, which extends over a temperature interval of perhaps 100 to 200° C., the so-called softening interval of an amorphous substance or glass, has hitherto been designated as the melting point of quartz. If the amorphous solid quartz glass be heated for a longer time at temperatures of 1,200° to 1,400° C., it devitrifies again quite gradually to tridymite with corresponding reduction of volume. The re-formation of tridymite from solid quartz glass corresponds to a volume decrease of 5·8 per cent. Tridymite was identified by its index of refraction 1·48, and by means of the heating microscope, with which it remains doubly refracting to 300° C. A. Lacroix found under analogous conditions of origin similar fine twinned crystals of tridymite in glassy inclusion in leucite-tephrite from Vesuvius.

By keeping the fluid quartz glass (produced at 1,800° to 2,000° C.) at 1,200° to 1,400° C. till devitrification results, cristobalite is formed. This was first recognised as such in devitrified quartz glass by A. Lacroix and described by F. E. Wright (*Zeits. f. anorg. Chem.*, 406, 1910, and 52, 1911). It was simultaneously found by P. J. Holmquist under quite analogous conditions of origin in molten Dinas bricks. Cristobalite has almost the same specific gravity—2·315 to 2·32—as tridymite, and only slightly higher index of refraction, $n=1·485$ to 1·49. The colourless cristobalite grains are intersected by perlitic cracks and exhibit very complicated twinning. With the heating microscope they are easily distinguished from tridymite, because at about 220° C. they become cubic (regular) and therefore isotropic, while tridymite remains doubly refracting up to high temperatures.

In the burning of Dinas bricks there is formed from the fine ground-mass and the 2 per cent. lime a calcium-aluminium-iron-silicate-glass, which

surrounds the various large non-plastic quartzite grains. The latter can be easily distinguished by means of the characteristic double refraction and the positive uniaxial interference figure. In separate places amorphous margins appear, which especially accompany the numerous fissures and cracks. The pea-sized quartzite grains only amount to about half the whole mass of the brick, and in burning about half to two-thirds of the possible volume increase is attained. Illustrations are given of the microscopic appearance of Dinas bricks, some of them after 10 or 50 charges in the Martin furnace. After 50 charges the brick consisted almost entirely of wedge-shaped twinned tridymite crystals, even the large grains of quartzite being mostly devitrified into tridymite. After 10 charges the brick showed the ground-mass for the most part devitrified, possibly involving a slight diminution of volume. The larger quartzite grains have at the same time become almost entirely isotropic quartz, the index of refraction of the isotropic mass being lower than that of tridymite. This transformation corresponds theoretically to a volume increase of about 20 per cent., but this by the previous burning had already occurred marginally, and by filling of the cracks becomes partly compensated.

The re-formation of tridymite from the amorphous quartz theoretically involves a volume decrease of 5·8 per cent., but this is not quite reached. The so-called tridymite Dinas bricks examined by the author have never changed their viscosity. But the very great furnace heat melts Dinas bricks, and stalactitic formations hang from the furnace roof—such as those in which Holmquist discovered cristobalite. The author by good fortune obtained a Dinas brick in which a crust 2 to 3 cms. thick had completely melted, but the remainder of which still possessed its original solidity unchanged. In this piece three zones were to be distinguished: the zone lying next to the furnace heat had become fluid and afterwards solidified to cristobalite. The crystallizing capacity of cristobalite accordingly seems to be tolerably great. The great similarity in the mode of origin of cristobalite and tridymite on the one hand and triclinic and hexagonal nepheline on the other hand is remarkable (v. A. S. Ginsberg in *Zeits. f. anorg. Chem.*, 1912, p. 277). The appearance of the different modifications seems to depend on the viscosity of the fusion. By heating in the thermal microscope and comparison with a specimen of the original substance (from Cerro San Cristobal) to which the name was applied, the author proved its identity with the natural cristobalite. The specific gravity of cristobalite grains purified with hydrochloric acid amounted to 2·315, the index of refraction was 1·49; at 220° C. it became regular (cubic); the transformation is reversible with difficulty. The cristobalite is separated from a yellow glass containing iron. In isolated places appear isolated longish yellowish prisms of medium double refraction, which perhaps might be iron carbide. Analysis of this first zone yielded 90 per cent. of silica. This diminution of silica is caused by volatilization. Since the zone is coloured grey by carbon, the volatilization of the silica is presumably favoured by intermediate formation of silicon monoxide or amorphous silicon carbide. The finely divided carbon particles will also act as centres of crystallization in the solidification of the molten Dinas brick, and in that way promote the crystallization of cristobalite. The author confirmed Blasberg's observation that this zone if held longer at high temperatures becomes clearer through combustion of the carbon. In the molten Dinas brick and in stalactites formed from them can often be recognised quartzite fragments still connected. A microscopic examination showed that these also, without having lost their connection, were entirely transformed into cristobalite.

The second zone corresponds to the typical constitution of a tridymite Dinas brick which in part still contains amorphous quartz. The characteristic wedges of twinned tridymite crystals have specific gravity 2·315 to 2·32, index of refraction 1·48, and continue doubly refracting in sections in the thermal microscope up to 300° C. The author could not find sections approximately perpendicular to the optical axis, which become isotropic at about 125° C. Towards zone I the brick is almost black. Ground dust from this border zone I to II shows tridymite wedges and cristobalite grains. Zone II apparently never changed its viscosity. In zone III the unchanged quartz fragments in

the quartzite grains increase. The large quartzite grains are often bounded marginally by a wreath of tridymite grains, by which a very firm structure is guaranteed. The third zone contains much still unchanged quartz, and quite resembles the constitution of a burned Dinas brick ready for sale. This brick presumably was derived from the roof of a Martin furnace and stood in communication with the cooling atmosphere. Otherwise the fact could scarcely be explained that after six months of continuous heating at temperatures above 1,600° C. so much unchanged quartz still appeared—even taking into account the very small conductivity for heat.

A series of quartzites from which Dinas bricks have been produced were investigated. They were burned 10 to 15 times at temperatures of 1,300° to 1,480° C. (about cone 11 to 18) and showed an average volume increase of 17 to 20 per cent. This agrees with Cramer's research. Under the microscope it could be seen that the quartzite, partially much broken down by the repeated burning, was almost completely transformed into the solid glassy isotropic amorphous condition. Only quite isolated portions still contained small fragments of unchanged quartz. In other pieces the very small characteristic wedges of the tridymite twins could be recognised. The index of refraction of the isotropic mass was lower than that of the tridymite crystals and could in individual cases be determined as 1·46. The index of refraction of the quartz glass produced from very pure rock crystal was for sodium light 1·458. The specific gravity of the isotropic particles of refractive index 1·46 was 2·23 to 2·25. That the value for pure quartz glass of specific gravity 2·21 is somewhat too high is explained by impurity and eventually adhering small tridymite crystals. The volume increase falls between the values of the volume increase in the transformation from quartz into tridymite (14·2 per cent.) and that of quartz into quartz glass (20 per cent.). In quartzites and Dinas bricks the enlargement of pores in the heating has also to be considered. J. M. Ogan traced the permanent expansion of firebricks to the formation of an impermeable vesicular structure, which results from single components of the clay volatilizing at high temperature, and so swelling out the molten glass and in that way causing it to expand. In small measure this phenomenon also plays a part in Dinas bricks under certain conditions, though it recedes behind the volume change stipulated by changes of physical conditions.

In conclusion, the applicability of quartzites of different geological origin for the manufacture of Dinas bricks was discussed. It is very generally recognised that as ground-mass a more or less impure quartzite must be taken, whilst for the pea-sized quartz grains a purer quartzite is preferred. The coarse quartzite fragments serve to raise the melting temperature and stability of Dinas bricks. P. J. Holmquist made the observation that quartz grains which, in the microscope between crosesd nicols show wave-like extinction, on burning in the furnace disintegrate into numerous particles. The dynamic pressure of rock strata to which the crystalline structure of quartz grains in rocks is sometimes exposed by geological folding processes is in this case undoubtedly the cause of such grains on heating disintegrating into very fine dust. As is well known quartz with small pressure perpendicular to the optical axis becomes biaxial. Its high resistance to compression was ascertained by F. Rinne. A quartz cube of 1 cm. edge, of which the surface under pressure is parallel to the base, stood a pressure of 15,364 kg. per square cm. and broke down under a pressure corresponding to a column of quartz about 57 km. in height. One cannot specify without further knowledge what pressure suffices to make quartzites useless for the manufacture of Dinas bricks. If by previous microscopic investigation wave-like extinction can be ascertained in the quartz grains, these quartzites will not be suited for the coarser quartz grains, as it must be apprehended that at higher temperatures they may disintegrate. A temporary pressure need not be shown in wave-like extinction.

There are nine illustrations representing microscopic appearances.

This article is substantially the same as the one in *Stahl und Eisen* referred to in Wernicke's paper. (See Trans., 17, *Abs.*, 3, 1918.)

ATTACK OF SLAGGING MATERIALS ON GROG.—Dr. Hirsch (*Bericht 32 ordentliche Hauptversammlung des Vereins deutscher Fabriken feuerfester Produkte*

E.V., 1912, p. 84). An illustrated account of experiments made to ascertain the effect of different slags on hollowed bricks or blocks made from five different body mixtures containing 50 per cent. of grog (20 fine, 15 granular, and 15 in pieces), the remainder being clay or 40 clay and 10 quartzite. The test-pieces were made at different temperatures, Seger cones 05a, 8, 12, 14 and 17. Cupola slags were used, and also Portland cement, and marble, the tests being made at cone 14. The chemical composition is given. It was distinctly recognised in the tests with cupola slag that the action of the slag increased with the amount of water used in making the test-pieces. The quartz grains were scarcely attacked by the cupola slag. In the case of the glassy slag formed when cement was used, analysis gave nearly the same results with different trials, the molecular formula for the glass being 2·5 to 3 CaO/ 1 Al_2O_3+3 SiO_2. Marble gave results very similar to those obtained from Portland cement, the lime in the glass corresponding to the upper limit (3 CaO). Details are given as to the action of the three materials on the several bodies, and the appearance of some microscopic sections is described and illustrated.

INDUSTRIAL EMPLOYMENT OF QUARTZ GLASS, ETC.—Pohl (*Bericht 32 ordentliche Hauptversammlung des Vereins deutscher Fabriken feuerfester Produkte E.V.*, 1912, p. 108). It is pointed out that whereas Dinas bricks made from vein quartz, quartz, sand, or other typical forms of quartz expand when strongly heated, and this expansion is not prevented by repeated burning, the case is different with the "Findlingsquartzit;" also called "Hornstein" (hornstone or chert), in which the coefficient of expansion is only small when strongly heated, and therefore this raw material is generally popular for the production of Dinas bricks. This "Hornstein" is not a pure crystalline substance, but is an extraordinarily dense, almost amorphous silica, concerning the origin of which geologists do not yet give quite a clear explanation. Some suppose "Hornstein" to be solidified from gelatinous silica, others count "Hornstein" among the volcanic eruptive rocks.

The behaviour of "Findlingsquartzit" with strong heating may have been the cause of producing objects from melted or fritted quartz, which, besides insensibility to the action of very strong acids (except phosphoric acid and hydrofluoric acid), was able to offer resistance to the highest temperatures and abrupt temperature fluctuations occurring in technical work to-day.

Rock crystal has a coefficient of expansion 0·00000781 in the direction of the principal axis, and 0·00001419 in a direction perpendicular to that.

Fused quartz on the other hand has a coefficient of expansion of only 0·00000059, only $^1/_{24}$ that of rock crystal. Unfortunately, the corresponding number for "Findlingsquartzit" is not available.

The first trials in the melting of quartz were undertaken in 1839 by the Frenchman Gaudin, who made use of the oxyhydrogen blowpipe, and he after great difficulties produced fused quartz from rock crystal; he made small rods, small balls, and small tubes from it. These trials were repeated by Gautier, without anything noteworthy being recorded.

About the year 1900, Boys, Dufour, Le Chatelier, Shenstone, Heræus and Schott gave greater attention to the production of quartz glass from rock crystal by melting with the oxyhydrogen blowpipe. Heræus made use of a crucible of iridium or zirconia, but the products were very expensive.

Shenstone and Hutton changed from the oxyhydrogen blowpipe to the electric arc, but with not very promising results to 1901. In 1902 Ruhstrat melted quartz in the electric furnace devised by himself, and Hutton also attained better results. In 1904 Bottomley and Paget's first patent was taken out, and by 1907 marketable goods were being produced, very pure quartz sand being substituted for the more expensive rock crystal, and this is now generally used. An illustrated description of the processes employed by the Thermal Syndicate, Ltd., at Wallsend, is given, followed by an account of the mode of production of different classes of articles from fused quartz.

HIGHLY REFRACTORY PORCELAINS.—Dr. Heinecke (*Berichte der Technisch-wissenschaftlichen Abteilung des Verbandes keramischer Gewerke in Deutschland*, I, 13, 1913). A clay is termed refractory when its melting point

lies above cone 26. The present article concerns the production of porcelains or porcelain-like masses whose melting point lies higher than this.

The refractoriness of highly refractory clays alone no longer suffices to satisfy requirements. Therefore calcined alumina is added to the refractory plastic clays, with a very small quantity of flux to give the necessary firmness. Masses have also been produced successfully from pure and impure magnesia with use of organic binding material, and alumina alone and other metallic oxides well known as highly refractory, as for example zirconia, have been formed into objects. The hitherto used highly refractory masses are not to be used for those purposes, in which at high temperatures the density and impermeability to gases and liquid substances is important, because with the means at present available they cannot be burned into a dense mass like porcelain.

By porcelain is understood in ceramic technology a clayware of mostly white appearance, which is burned dense to sintering and the fracture of which is glassy. We are further accustomed to associate with the notion of porcelain the demand for a certain permeability to light, it should be translucent; but since this property mostly depends, besides on the burning temperature applied, on the content of the mass in felspar and quartz, many burned masses claiming to be porcelains according to their process of production show this property only in small degree or even not at all.

As ground formula for the mass of European hard porcelain the composition of 50 clay substance, 25 felspar, and 25 quartz is taken by tacit agreement in German technics, and by diverse variations of these numbers the entire series of mixtures for the different porcelains and even for the earthenwares can be obtained. It is also well-known that in the porcelain mass the clay substance is the refractory material, felspar is the flux, and quartz serves in the first place as plasticity-reducing material; that further the quartz above the melting point of felspar with further advance of the temperature is according to the degree of its fine distribution in the mass gradually dissolved in the remaining ingredients of the mass; that the quartz must thus be regarded as an ingredient promoting fusibility of the mixture.

For increasing refractoriness therefore some other refractory material may be substituted for quartz in hard porcelain, and, on account of its high refractoriness and its low solubility in melted felspar in presence of clay substance, alumina is suggested. The alumina should be previously calcined as strongly as possible, in the sharpest fire of the porcelain ovens (cone 18), or still better by melting electrically, in order that no further contraction may take place subsequently. Unfortunately this last method is not practicable on a large scale because of cost; the melted alumina obtained as by-product in the Goldschmidt process or that melted on a large scale at Rheinheld is unfortunately not pure enough for objects depending on special purity of materials like apparatus for scientific purposes.

The increase of refractoriness by the introduction of alumina into the mass, as shown by trials, is further enhanced if the quantity of clay substance is made as small as the working of the mass allows. With Zettlitz kaolin as binding material, and the shaping by moulding and turning, this limit lies at a content of about 30 per cent. clay substance. This gives a mass of 30 parts Zettlitz kaolin, 25 parts felspar, and 45 parts strongly calcined alumina. This mass burns to a close texture at the usual finishing temperature of hard porcelain, and has the very high melting point of cone 35—36. Further it is useful for various purposes, as trials have shown, because, for example, melting silicates attack it much less easily than masses richer in silica. In spite of its high melting point its use for refractory purposes is restricted, because the mass on account of its high felspar content begins to soften at a not very high temperature, at which hard porcelain with the same content of felspar also softens.

It was to be hoped that this objection to its use at high temperatures would be removed as soon as a flux was found which possesses a considerably higher melting point than felspar, but which would not be too high to prevent the use of hard porcelain ovens, with a maximum temperature of cone 18, for

burning the objects. Such a flux was found in an intimate mixture of alumina and felspar, which was produced by protracted grinding, and which was calcined several times at the highest temperature of the porcelain oven.

Mixtures were made with 2, 3, 4, and 5 molecules of alumina and one molecule of felspar, giving the following compositions and melting points:—

1.	$3Al_2O_3.K_2O.6SiO_2$	Melting point	cone	12
2.	$4Al_2O_3.K_2O.6SiO_2$	,,	,,	12
3.	$5Al_2O_3.K_2O.6SiO_2$	,,	,,	13—14
4.	$6Al_2O_3.K_2O.6SiO_2$	,,	,,	15

From this it was assumed that frits 3 and 4 could produce a suitable flux if added in appropriate amount, and that frit 3 would be preferable. A mixture of 350 parts of frit 3, 300 parts Zettlitz kaolin and 350 parts strongly calcined alumina gave a rather short mass, but it was plastic enough to be worked by the usual means. Objects produced from this mass, burned in the porcelain oven, were gas-tight, and the bending was comparatively small at cone 16—17. The melting point of the mass was very high, measurably above cone 36, estimated at cone 38. The mass is only translucent on the fractured edges, and is very hard and tough. The mass has a drying contraction of 3·5 per cent., a firing contraction in the strongest porcelain fire of 14·9 per cent., making a total of 18 per cent. The porosity test gave a water absorption of 0·05 per cent. Some articles were made for requirements at higher temperatures; the results of trials, which justify a positive opinion as to the utility of the new porcelain, are held over.

In an earlier published communication it is shown that a dense and translucent mass, externally resembling porcelain, is produced from an intimate mixture of alumina and magnesia. For such a mass it is ascertained that a mixture in the molecular proportions of alumina to magnesia as 1 : 3 is appropriate. The mixture is strongly calcined in the porcelain oven, pulverised, again finely ground and once more calcined. After repeating this a third time the mass is then mixed as fine powder with 5 per cent. rye flour and 3 per cent. salep solution to a plastic mass. The melting point is at cone 37, and the finishing temperature for firing this mass is cone 32. As the mass burns dense, and is free from silica, it is useful for many purposes in which these properties are depended on.

The very high burning temperature has hitherto not permitted the production of larger vessels from this material, as results on a large scale are unreliable at that temperature. The vessels hitherto produced could not be made dense if any larger than the author's small round gas blowpipe blast muffle furnace.

It was assumed that the density of the mass is produced by the formation of a compound of alumina and magnesia similar to spinel, which has a lower melting point than pure magnesia, and that this compound cements together the rest of the magnesia. Whether the formation of spinel actually took place or not cannot be decided.

An intimate mixture of alumina and calcined lime was produced by prolonged grinding together, and after calcining at cone 18 was ground with strongly calcined magnesia. From this was produced at porcelain oven heat a dense mass, strongly translucent, which may be used as binding or cementing material for magnesia and alumina. The best proportions are not yet decided, but a later communication on this point is promised.

CLAYS AND SHALES OF SOUTHERN MANITOBA.—(Summary Report of Mines Branch of Department of Mines, Ottawa, 117, 1916). Notes on tests.

CLAYS OF SOUTH SASKATCHEWAN.—(Summary Report of Mines Branch of Department of Mines, Ottawa, 119, 1916). A report of field work, with results of tests, on refractory and semi-refractory clays.

CANADIAN KAOLIN PRODUCTS.—(Summary Report of Mines Branch of Department of Mines, Ottawa, 105, 1916). Deposits of residual clay resulting

from decomposition of rocks in situ are rare in Canada, owing to scouring of most of the country by Glacial ice. The only workable kaolin deposit at present known in Canada is at St. Remi d'Amherst, Argenteuil County, and the kaolin is confined to vertical dikes or veins, the main vein being 20 to 40 feet wide, and the smaller veins 1 or 2 feet. The enclosing walls of shattered quartzite are impregnated with kaolin for a considerable distance from the main veins. In the upper part of the dikes there is much yellow or pink kaolin. The yellow clay on analysis gave 54·24 per cent. silica, 34·24 alumina, 2·04 iron oxide, 2·54 lime, 0·46 magnesia, with 5·87 loss on ignition. A sample of this clay was not deformed at the softening point of cone 25, but a washed sample of the same clay failed at cone 15. The crude yellow clay is rather short grained and weak in the raw state, and its shrinkage is excessive. Admixture of some white clay with the yellow improves the refractory qualities.

A mixture of the white kaolin with 10 to 20 per cent. of a common brick clay gives good dense firebricks, shrinkage being kept within limits by calcining part of the clay before making the bricks.

The crushed quartzite was found to contain an average of 11 per cent. of foreign material (mostly kaolin). After passing a 10-mesh screen, milling with a little water, and pressing into bricklets, the material was burned in a gas kiln to 1,300° C., then in a carbon resistance kiln to 1,530° C. The bricklets were hard and dense, showing a fused bond between the kaolin and the quartz. Raising the temperature of part of a bricklet to 1,650° C. only slightly changed the material, without any indication of sintering, the superficial quartzite grains being still angular. Similar full-size bricks were tested in the ports of steel furnaces with highly satisfactory results.

Material resembling Cornish stone was also found at St. Remi, but no ball clay has hitherto been found in Canada.

The St. Remi china clay is of high grade, but there is no native plastic clay to use with it for producing whiteware bodies.

MAGNESITE DEPOSITS IN CANADA.—M. E. Wilson (Memoir 98 of the Canada Department of Mines, No. 81, Geological Series). An account of magnesite deposits of Grenville District, Argenteuil County, Quebec. These deposits resemble in appearance and mode of occurrence the magnesites of Austria-Hungary.

The Steel Company of Canada has recently been using calcined Grenville magnesite mixed with 10 to 40 per cent. furnace slag as a lining for open hearth steel furnaces, with satisfactory results. The slag analysis showed 9·81 per cent. silica, 1·78 alumina, 17·29 oxide of iron, 51·97 lime, 6·74 magnesia, 2·70 phosphoric acid, 0·247 sulphur, 5·67 oxide of manganese. For this purpose the furnace is heated beyond the melting point of the slag (about 1,480° to 1,540° C.), and small charges of the mixture of crushed slag and broken partially calcined magnesite are thrown and spread uniformly over the furnace bottom at intervals of 15 minutes. If carefully laid and intimately mixed this bottom will last for a considerable length of time without repair, and is equal in every respect to bottoms prepared from Austrian magnesite.

It is reported that a mixture of dead-burned Grenville magnesite, caustic calcined Grenville magnesite, and magnesium chloride is now being satisfactorily employed as a furnace lining to replace magnesite bricks.

Foreign sources of magnesite are briefly reviewed, typical analyses being given along with other particulars. Short notices of other Canadian deposits are also included, not only of magnesites, but also of the hydromagnesites of British Columbia.

The Grenville magnesite occurs in connection with quartzite, garnet-sillimanite gneiss, crystalline limestone, and sometimes with pyroxenite rocks. It is a glistening cream white to milk white or grey material occurring in extensive masses associated with bands or lenses of dark green to light yellow serpentine, and nearly everywhere contains some included dolomite, which is usually difficult to distinguish. The minerals present in the magnesite deposits, named in order of abundance, are magnesite, serpentine, dolomite, diopside, phlogopite, quartz, talc, pyrites, sphalerite, magnetite, and graphite. The mode of occurrence and distinguishing characters of each are described.

Medium to fine-grained glistening magnesite usually contains between 7 to 12 per cent. of lime. Grey magnesite generally contains still more lime. Dull white material and coarsely crystalline material are usually dolomite, and contain 30 per cent. of lime.

Detailed descriptions are given of the different deposits, with tables and a number of illustrations, including coloured diagrams on three loose sheets.

HOT AND COLD SIZES OF FIREBRICKS.—J. W. Mellor (*Trans. Inst. Gas Eng.*, 115, 1917). See TRANS., 16, 270, 1917, where the paper is reprinted by permission.

AFTER-CONTRACTION OR AFTER-EXPANSION OF FIREBRICKS IN OXIDIZING AND REDUCING ATMOSPHERES.—J. W. Mellor (*Trans. Inst. Gas Eng.*, 118, 1917). See TRANS., 16, 268, 1917, where the paper is reprinted by permission.

STANDARD SPECIFICATION FOR REFRACTORY MATERIALS.—(*Trans. Inst. Gas Eng.*, 111, 1917). Two alterations have been made in the specification relating to retort material. Clause 1 now reads: The retorts or retort tiles shall be made of sufficiently seasoned raw clay compounded with clean burnt clay or grog. They may also be made from suitable silica material. No " grog " should be used which will pass through a test sieve having sixteen meshes to the linear inch. In view of the experience gained, it has now been agreed that, in addition to a minimum porosity of 18 per cent., a maximum porosity of 30 per cent. shall be specified.

COMPRESSION TESTS OF BUILDING TILES.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 338, 1917). Tests intended to be applied to tiles commonly used for walls and partitions. Tabulated results of tests are appended.

ABSORPTION TESTS OF BUILDING TILES.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 353, 1917). Tests to be applied to tiles similar to preceding. Tabulated results appended.

COMPRESSIVE STRENGTH OF PORTLAND-CEMENT MORTARS.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 630, 1917). Tentative standard specifications and tests for pieces composed of 1 part cement and 3 parts standard sand.

CLAY SEWER PIPES.—(*Proc Amer. Soc. for Testing Materials*, 17, Pt. I, 634, 1917). Tentative specifications and tests.

CEMENT-CONCRETE SEWER PIPES.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 647, 1917). Tentative specifications and tests. Following on p. 659 are tentative specifications for required safe crushing strengths of sewer pipes.

REFRACTORY MATERIALS UNDER LOAD AT HIGH TEMPERATURES.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. 1, 665, 1917). Tentative test for resistance to deformation at specified temperature for specified time under load of 25 lb. per square inch. The furnace and loading device are figured.

SLAGGING ACTION OF REFRACTORY MATERIALS.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 669, 1917). Tentative test, using suitable slag of specified composition.

APPARENT SPECIFIC GRAVITY OF COARSE AGGREGATES.—*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 776, 1917). Tentative test. Sample dried to constant weight, cooled, and weighed to nearest half gm. (=weight A). Sample immersed in water for 24 hours, surfaces dried with towel or blotting paper, and again weighed (=weight B). Then weighed in wire basket suspended in water from balance. Difference between this and weight of empty basket suspended in water gives weight C. = weight of saturated sample immersed in water. Apparent specific gravity then $= A/(B-C)$.

APPARENT SPECIFIC GRAVITY OF NON-HOMOGENEOUS FINE AGGREGATES.—A. S. Rea (*Proc. Amer. Soc. for Testing Materials*, 17, Pt. II, 256, 1917). See abstract of *Preprint*, TRANS., 16, *Abs.*, 62, 1917.

HEAT-INSULATING PROPERTIES OF BUILDING MATERIALS.—W. A. Hull (*Proc. Amer. Soc. for Testing Materials*, 17, Pt. II, 422, 1917). See abstract of *Preprint*, TRANS., 16, *Abs.*, 124, 1917.

FAILURE OF 30-INCH TILE DRAIN.—R. W. Crum (*Proc. Amer. Soc. for Testing Materials*, 17, Pt. II, 453, 1917). An investigation of a case of failure, with special reference to standard specifications.

MANUFACTURE OF SILICA BRICKS.—C. E. Nesbitt and M. L. Bell (*Proc. Amer. Soc. for Testing Materials*, 17, Pt. II, 467, 1917). Suggested improvements in the manufacture, especially with reference to size of grain and power pressing. See abstract of *Preprint*, TRANS., 16, *Abs.*, 76, 1917. A discussion follows.

MOULDED INSULATING MATERIALS.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 778, 1917). Tentative tests for strength, dielectric strength, distortion under heat, and effect of moisture.

CLAY DEPOSITS OF ILLINOIS.—S. St. Clair (Extract from Geol. Survey Bull. No. 36, 1917). An account of fireclay deposits near Mountain Glen, Union County, Illinois, U.S.A., including chief properties, results of tests, analyses, etc. The clay is a very fine-grained, plastic, strong, highly refractory bond clay, and has been found satisfactory for making graphite crucibles and glass pots.

CLAYS AND SHALES IN ILLINOIS COAL MINES.—R. T. Stull and R. K. Hursh (Illinois State Geol. Survey, Bull 18, 1917). Physical and burning tests were made on 106 samples of floor clays and roof shales, of which 52 were found to be adapted for manufacturing clay products; 5 were of doubtful value, and 49 were useless for this purpose.

PROPERTIES OF SOME AMERICAN BOND CLAYS.—A. V. Bleininger and G. A. Loomis (*Trans. Amer. Cer. Soc.*, 19, 601, 1917). A comprehensive record of tests made on samples of American plastic bond clays, with special reference to their possible use for glass refractories, graphite crucibles, and similar products. For the sake of comparison several English (ball clay) and German (Klingenberg and Gross Almerode) clays were included in the series.

The authors emphasize the fact that in nearly every case the use of an intimately blended mixture of suitable clays is preferable to using single clays. In this way it should be possible to produce from native clays bodies possessing all the desired properties. For glass refractories a siliceous clay should be used as the basis, reinforced by the addition of suitable dense burning materials.

There must be many clays in the U.S. of the bond clay type. There are also plastic kaolins, which, though not contributing towards the strength of the body, are very effective in increasing refractoriness and raising the over-firing temperature. The use of Georgia and Florida kaolins, up to 20 per cent. of the total clay, has been found very effective for high grade bodies.

POROSITY-VOLUME CHANGES OF SOME PORCELAIN BODIES.—G. A. Loomis (*Trans. Amer. Cer. Soc.*, 19, 636, 1917). The temperature-porosity-volume-change curves of 5 felspathic porcelain bodies are given, and deductions made as to maturing temperatures, temperatures at which over-firing begins, vitrification ranges, with a short discussion concerning the indications.

DEFORMATION STUDY OF MgO-Al_2O_3-SiO_2 MIXTURES.—A. S. Watts (*Trans. Amer. Cer. Soc.*, 19, 453, 1917). The most fusible mixture was 20 per cent. MgO, 20 per cent. Al_2O_3, 60 per cent. SiO_2 ($=MgO\text{-}0{\cdot}392\ Al_2O_3\text{-}2{\cdot}0\ SiO_2$), the deformation temperature being cone 12, and the deformation process being very rapid. A slight increase of temperature caused the deformation of a

mixture having the composition 25 of MgO, 15 of Al_2O_3, and 60 of SiO_2, and almost simultaneously of a mixture having the composition 20 of MgO, 15 of Al_2O_3, and 65 of SiO_2. These three mixtures deform after cone 12 but before cone 13 starts. With the first evidence of fusion of cone 13 the following mixtures begin to deform, and their deformation is complete before cone 13 is half down, viz. :—15 of MgO with 15 of Al_2O_3 and 70 of SiO_2, 15 of MgO with 20 of Al_2O_3 and 65 of SiO_2, 25 of MgO with 10 of Al_2O_3 and 65 of SiO_2, 25 of MgO with 20 of Al_2O_3 and 55 of SiO_2.

At cone 8, mixtures with 40 per cent. or less of silica began to curl, but soon stopped altogether. At cone 10 a pronounced shrinking was noticed in certain members with 35 per cent. or more MgO, 10 per cent. or more Al_2O_3, and 30 per cent. or more SiO_2. At cone 13 (started) trials with 45 per cent. or more MgO were less than half their original size. Mixtures containing 5 to 15 per cent. of Al_2O_3, 35 to 50 of MgO, and 45 to 60 of SiO_2 were found to be highly translucent and to show no trace of warping.

DEFORMATION STUDY OF BaO-Al_2O_3-SiO_2 MIXTURES.—A. S. Watts (*Trans. Amer. Cer. Soc.*, 19, 457, 1917). A similar investigation to the preceding. The deformation eutectic is either the mixture with 35 per cent. of BaO, 10 of Al_2O_3, and 55 of SiO_2, or the mixture with 40 of BaO, 10 of Al_2O_3, and 50 of SiO_2, both deforming completely at cone 6 down. The choice depends upon the state of deformation which is taken as the finishing point. The next to deform (at about cone 7) were mixtures with 35 of BaO and 5 of Al_2O_3, 40 of BaO and 5 of Al_2O_3, 45 of BaO and 5 of Al_2O_3, 50 BaO and 5 of Al_2O_3, and 45 of BaO and 10 of Al_2O_3 respectively. Up to cone 10 no mixture of BaO and SiO_2 without Al_2O_3 deformed or vitrified. All mixtures with 5 per cent. Al_2O_3 showed a marked opacity. Those containing 10 per cent. Al_2O_3 were either clear or tended to form clear glasses.

VOLUME CHANGES OF SOME COMMERCIAL SILICA BRICKS ON HEATING.—D. W. Ross (*Trans. Amer. Cer. Soc.*, 19, 83, 1917). Practically all silica bricks now made in the United States contain at least 96 per cent. silica. They are manufactured by crushing quartzite so that the coarsest particles are about ¼ inch across, and adding 2 per cent. of lime as milk of lime, and enough water for the material to be hand moulded in steel moulds. When dry the bricks are slowly burned to about cone 18. The α-β cristobalite inversion, which occurs between 220° C. and 300° C. is accompanied by a volume change of about 3 per cent. The α-β quartz inversion at 575° C. is accompanied by a volume change of about 1·4 per cent. These two volume changes tend to cause cracking and spalling when cold silica bricks are heated rapidly, and again when cooled; this is largely overcome by more gradual heating and cooling. As tridymite does not exhibit any large sudden volume change, the alteration of any material to tridymite lessens the tendency of the brick to crack on heating. Slow burning allows a brick to become thoroughly bonded so that it can later withstand the shocks of sudden heating and cooling. Hence determination of permanent expansion produced on reheating silica bricks gives a measure of the degree to which they have been burned.

The author ascertained the results of reheating silica bricks of various makes to 1,400° C., 1,450° C., and 1,500° C. respectively. In general the porosity was increased by the heat treatments, and usually the greater the volume change the greater the increase in porosity. Increase in pore space is in general caused by increase in the volume of the solid material, the voids increasing as the volume of the solid material increases. A tendency of the material to crack on rapid heating or cooling, etc., is frequently (perhaps always) the cause of another slight increase in porosity, but such increases are usually negligible. The opposite tendency of the particles to flux and draw closer together is of minor importance and is only apparent in certain cases of well-burned brick. The increase in pore space is roughly proportional to the increase in volume of the solid material.

The percentage outside volume increase was greater with lightly burned

bricks than with others, and bricks which had nearly reached equilibrium showed in one instance a volume contraction at 1,500° C.

Commercial burning of silica brick seldom exceeds 1,450° C.

Bricks made from very similar materials showed a wide variation in porosity.

The specific gravities of artificial tridymite and cristobalite are approximately 2·270 and 2·333 respectively. To approximately determine the degree of burning it is only necessary to find the specific gravity of a piece of the manufactured brick from the relationship,

$$\text{Specific gravity} = \frac{\text{dry wt.}}{(\text{wet. wt.} - \text{sus. wt.}) - (\text{wet wt.} - \text{dry wt.})}$$

that is by dividing the dry weight of the piece by the volume of the solid material, *i.e.*, by exterior volume minus pore volume. This method might readily be used for inspection work at plants where quick results are needed. The average specific gravity of bricks from ten different works was 2·3546 after once firing at 1,400° C., the average volume expansion being 1·45 per cent. The average volume expansion of two series of 14 each, fired once at 1,450° C. and 1,500° C. was 1·38 and 5·66 per cent. respectively. This method of determining the degree of burning has the advantage over the "outside volume increase" method in that it deals only with the solid material and hence is independent of any porosity changes.

Underburned bricks increase both in porosity and outside volume when reheated to 1,400°—1,500° C., and the increase in porosity is roughly proportional to the increase in volume of the solid material. With material that has nearly reached equilibrium at 1,450° there is little change on reheating.

A means of testing the quality of silica refractories is available by comparing the percentage volume increase of materials which have been repeated (once or oftener). The extreme porosities 22·64 and 31·96 per cent. (of original brick) show the range likely to be found in industrial practice. A combination of the volume and specific gravity methods should afford the means of determining accurately whether or not silica refractories have been fired to the proper temperature.

LATENT HEATS OF FUSION OF LIME AND MAGNESIA.—E. W. Washburn (*Trans. Amer. Cer. Soc.*, 19, 195, 1917). The factors which determine the ease or difficulty with which a material can be liquefied are (1) its melting point, (2) the quantity of heat which it absorbs in melting, that is, its latent heat of fusion, and (3) to some extent, its thermal conductivity. It is possible for one material to be more easily fusible than another material which has a lower melting point. There are at present practically no reliable data on the heats of fusion of refractory materials. Several methods available for determining latent heat of fusion are briefly discussed, but the only one considered with reference to the present case is the application of the law which expresses the relation between the composition of a mutual solution of two similar materials and the temperature at which that solution will be in equilibrium with pure crystals of either of its constituents. This law is expressed by the equations:

$$\log_{10} x_a = \frac{0{\cdot}219 L_a (T_a - T)}{T_a T} \quad \text{and} \quad \log_{10} x_b = \frac{0{\cdot}219 L_b (T_b - T)}{T_b T}$$

where x_a and x_b represent respectively the ratios of the number of molecules of the two substances (A and B) to the total number of molecules, L_a and L_b represent respectively the latent heats of fusion of one gram-molecular-weight (called one *mole*) of each of the materials, T_a and T_b represent respectively the melting points of the two pure materials on the absolute centigrade scale, and T similarly represents the eutectic temperature of the system. Examples are given to show that this law applies accurately in other cases. In the case of lime and magnesia the melting point diagram is apparently of the simplest possible type showing one eutectic, no compounds, and no mixed crystals. The composition of the eutectic melt was found to be 67 per cent. of lime and 33 per cent. of magnesia, the eutectic temperature being 2,300° ±

50° C. The substitution of these values in the foregoing equations gives the latent heat of fusion of lime as 28,000 (±20 per cent.) calories per mole or 490 calories per gram, and for the latent heat of fusion of magnesia 28,000 (±15 per cent.) calories per mole or 700 calories per gram. These are much higher that the known heats of fusion of any other materials, including the minerals anorthite, diopside, enstatite, and olivine, and the low fusibility of lime and magnesia is evidently largely due to the great amount of heat which they absorb on melting.

THE BURNING PROPERTIES OF SOME AMERICAN REFRACTORY CLAYS.—H. G. Schurecht (*Trans. Amer. Cer. Soc.*, 19, 248, 1917). An account of tests made with Georgia kaolin, Kentucky ball clay, Mount Savage flint clay, and Mount Savage plastic fireclay. It was found that the load-carrying capacity of refractory clays can be increased by burning them to higher temperatures, the improvement being greater in open-burning clays, and less in clays which vitrify at lower temperatures (like the plastic fireclay and the ball clay). The fire shrinkage is in some cases reduced by burning the clay to as high a temperature as possible, especially with the plastic fireclay. The apparent porosity, volume shrinkage, deformation, and breaking temperature are given in a table, and also shown graphically in a diagram.

A NEW PRINCIPLE IN TEMPERATURE MEASUREMENT.—W. C. Harter (*Trans. Amer. Cer. Soc.*, 19, 260, 1917). An account of Dr. E. F. Northrup's new "pyrovolter principle," as applied to the measurement of high temperatures. The pyrovolter is an instrument which indicates temperature direct on a scale, like the ordinary deflection pyrometer indicator, but reads electromotive force instead of current, and therefore (like the potentiometer) gives readings which are independent of the resistance of the circuit in which the electromotive force is located—that is, independent of the outside lead resistance. The accuracy of the readings will therefore not be affected by the length of the lead wires coming from thermocouples to an instrument (pyrovolter). It is also immaterial whether the thermocouple is new (and of low resistance) or old and corroded.

The pyrovolter has no temperature coefficient of resistance, so change of temperature at the instrument does not affect its readings. This is due to the use of manganin wire in the part of the pyrovolter which determines the range of the instrument. One instrument can be adapted to read from both base-metal and noble metal couples, using the full scale for each. The deflection meter used is of the strong spring control, double pivot type of low resistance millivoltmeter. The working is explained with the aid of diagrams. It is possible to adapt any deflection instrument to the pyrovolter principle, and any kind of electrical meter operating on the d'Arsonval principle, without affecting its usefulness in its original capacity.

EFFECT OF THE SIZE OF GROG IN FIRECLAY BODIES.—F. A. Kirkpatrick (*Trans. Amer. Cer. Soc.*, 19, 268, 1917). An account of an elaborate investigation of the effects of using various proportions of grog of different sized grains, made into a body composed of half grog (by weight) and half plastic fireclay (ground to pass a 20-mesh screen). Trials were burned at cones 10, 12, and 14, the temperature rising 25° C. per hour, with 2 hours soaking at the end. Some of the trials were reheated a number of times, being quenched in cold water after each heating. A trial burn was also made with bodies containing the six separated sizes of grog (4—8 mesh, 8—12, 12—20, 20—40, 40—80, 80—dust), with equal weight of clay and a body consisting of the clay alone.

Results from single separated sizes are shown in diagrams—porosity, strength—porosity of raw bodies, strength—surface factor in raw and burned states, surface factor—quenching tests. The 80—dust body has a greater rate of vitrification than any of the other grog bodies, the 80-mesh grog apparently forming a dividing line between coarse or slowly vitrifying and fine or rapidly vitrifying grog sizes. Hence, at commercial burning temperatures, some fine grog is needed to give high strength by vitrification. From 4—8 mesh

to 40—80 mesh grog, strength increased with increase of porosity (due probably to cracks developed in drying). From 40—80 mesh to 80—dust strength decreased in the usual order with increase of porosity. Strength increased with increase of surface factor (calculated by Purdy's method). Porosity in the raw and burned states was a maximum in the 40—80 mesh body. Bodies with the larger sizes of grog withstood the quenching tests best.

Results from mixtures of sizes of grog are similarly shown in diagrams. Strength increased with increase of surface factor in bodies with coarser grog (down to 20—40 mesh), but not in those from 12—20 mesh down to 80—dust. Strength increased with increase of porosity in trials with grog not below 80-mesh (that is, with no dust), but in trials containing a mixture of 20—40, 40—80, and 80—dust grog, strength increased with decrease of porosity. The foregoing results from mixtures apply only to raw bodies. In the burned trials (at cone 12) from body with 4—8 mesh grog to bodies with 12—80 mesh grog strength increases with increase of porosity (due to small cracks formed in drying and not healed in burning). But in bodies with 20—dust grog and some bodies with 12—80 grog strength decreases with increase in porosity, the degree of vitrification being the governing factor. In bodies containing 4—20, 20—80, and 80—dust grog there is no relation between porosity and modulus of rupture (strength). Thus porosity may give wrong indications of strength in the case of bodies containing grog of different sizes. But surface factor affords an accurate means of judging the strength of such bodies. Curves in which surface factor of the grog portion of the bodies is plotted against modulus of rupture are of parabolic form in the lower portion, and straight lines in the upper portion. The relation is less exact in bodies containing 4—20, 20—80, and 80—dust grog, because these contain comparatively large particles which are dissolved by the clay to a much less extent than the small particles.

In quenching tests, bodies containing 8—40 mesh grog in the proper proportions withstood the treatment best, from 50 to 60 per cent. of the strength being retained. In general, increase of surface factor causes decrease in resistance to sudden heating and cooling. Four standard size firebricks containing small-sized grog (20-mesh and finer) cracked in two on the average at the 7th treatment. Two firebricks containing large-sized grog (about $\frac{1}{4}$ in.) cracked or spalled on the average upon the 25th treatment.

Two conditions are necessary to obtain fireclay bodies having greatest strength in the raw state: (1) The grog must not be too large so that it forms cracks, or planes of weakness, the clay being unable to bind such large particles together perfectly. (2) The grog must be so proportioned that the smaller sizes fill the voids between the larger particles, giving maximum density and strength. These conditions are met in bodies with 20—40, 40—80, 80—dust grog, the grog portions of the strongest bodies having the following limits of composition: 25 to $66^2/_3$ per cent. 20—40 grog, 0 to 25 per cent. 40—80 grog, and $33^1/_3$ to $66^2/_3$ per cent. 80—dust grog.

The rate of increase of strength increased with the temperature of burning. No relation was found between strength in the raw state and in the burned state. Grog for glass pots, etc., may contain too much fine or intermediate sized material causing low strength and cracking in drying.

Where screening into separate sizes and recombining is not economical, this may be accomplished by control of the conditions of grinding, as time, size of openings in screen plates, pressure, etc.

Applying the results to the production of saggars, the mixtures best adapted for (*a*) bodies where resistance to repeated heating and cooling is desired more than strength, and (*b*) bodies of greater strength obtained by sacrificing resistance to repeated heating, are singled out. The bodies (*a*) contain 4—8 mesh grog, 8—12 mesh grog, and 12—20 mesh grog in the proportions 1 : 2 : 2 and 1 : 3 : 1 respectively, and 8—12 mesh grog, 12—20 mesh grog, and 20—40 mesh grog in the proportions 1 : 1 : 3 and 1 : 1 : 1 respectively in addition to clay. The bodies (*b*) contain 12—20 mesh grog, 20—40 mesh grog, and 40—80 mesh grog in the proportions 2 : 1 : 0, 3 : 1 : 1, 2 : 2 : 1, 1 : 2 : 0, 1 : 3 : 1, 0 : 2 : 1, as well as the first or second size alone. In the bodies (*b*) the modulus of rupture ranged from 1,654 to 2,695 lb. per square inch.

RELATION BETWEEN THE FUSION POINT AND THE COMPOSITION OF REFRACTORY CLAYS.—R. J. Montgomery and C. E. Fulton (*Trans. Amer. Cer. Soc.*, 19, 303, 1917). A review of the results of tests of numerous refractory clays and some silica-clay mixtures, to trace the relative influence of silica, alumina, and the basic fluxes on the softening point (fusion point). The composition and fusion points (in cones) are given in tables, and the relations between softening points and composition are set out in diagrams, Sosman's silica-alumina melting-point curve being added for comparison. It is indicated that the analysis may show the limit of refractoriness of a clay, and that the silica-alumina ratio is the determining factor of fundamental importance. With the silica clay mixtures (in which only two clays were used) the melting-point curve is followed very closely, but the fusion point of many of the clays falls considerably below this curve, largely owing to the basic fluxes present, as the fineness is very nearly the same in all cases. The increased fluxing effect of the same percentage of base is noticeable in the case of a high silica low alumina clay. This effect of small percentages of fluxes probably attain its maximum with 14 to 18 per cent. alumina. With less than 8 per cent. alumina the effect of the fluxes decreases quite rapidly as the alumina decreases.

The main points brought out are: (1) The silica-almuina melting-point curve limits the refractoriness of a clay. (2) The drop below this curve in cones depends primarily upon the percentage of flux present. (3) As the amount of flux increases, its activity increases rapidly. (4) About 14 to 18 per cent. alumina (based on alumina plus silica=100) will give the maximum activity of the fluxes present. (5) With high silica beyond the eutectic point the activity of the fluxes decreases rapidly.

SPECIAL REFRACTORIES—MARQUARDT PORCELAIN AND MAGNESIUM ALUMINATE.—F. H. Riddle (*Trans. Amer. Cer. Soc.*, 19, 397, 1917). Reports a continuation of Bureau of Standards work published in vol. 18 (by W. L. Howat). See TRANS., 16, *Abs.*, 104, 1917). Has special reference to pyrometer tubes.

Magnesium aluminate (or spinel) crucibles are not easily attacked by molten slag or iron so long as the exposed surfaces are dense and free from blemishes. The crucibles will not stand exceedingly rapid cooling, but will stand ordinary usage. Special furnace linings, crucibles, tubes, boats, etc., can be made, which should be very refractory and not easily attacked by gases. The fusion temperature is 2,135° C. $\pm$20°.

MODIFIED LOAD TEST FOR FIREBRICK.—J. B. Shaw (*Trans. Amer. Cer. Soc.*, 19, 498, 1917). A special furnace and apparatus is described and figured, designed so as to admit of close comparison of high grade firebricks, and also to show more about a brick's behaviour than that it stands or fails. Results for magnesite, silica, carborundum, bricks, etc., are shown in curves. Reference is made to Bleininger and Brown's load test for firebrick, described in 1910, in which the load is constant, whereas in the new test the load decreases (through the automatic action of a spring) as the brick crushes. The author believes that by the modified test firebricks can be satisfactorily classified as to their load-carrying capacity. The results of this test give mathematically the relative behaviour of firebricks at different temperatures under load. It is recommended to turn the apparatus upside down, applying the load from the top, so as to facilitate setting the brick vertically and getting the direction of the load perfectly parallel to the long axis of the brick.

DUST PRESSED TILES.—F. W. Walker, Jr. and E. G. Kerr (*Trans. Amer. Cer. Soc.*, 19, 409, 1917). The four principal causes of variation in porosity of biscuit wall tiles are variations in body composition, firing, moisture content of green body and the pressure applied in shaping the tiles. The first two of these being kept practically constant, the effects of variations in the other two were investigated.

After the second lick, or following the expulsion of the air from the dust, the decrease in porosity for any repetition of the same pressure is continuous,

but decreasing in amount with increase in total pressure per square inch. When pressure per square inch is low the variation in porosity for any slight change in pressure is considerable, but with the higher pressures the variation is of secondary importance in securing uniformity to that of the moisture content. The effect of a variation in moisture content upon porosity proves to be considerable throughout the range of the investigation, and is of about equal extent in the case of the high and low pressure trials with a decrease in the case of pressures about that of the average hand operated press. Pressures below this give a decrease in the porosity with increase in moisture content, but above this pressure an increase in porosity. The various results are represented by curves, including pressure-shrinkage curves, besides tables giving the actual measurements.

INSTRUMENT FOR MEASURING PLASTICITY.—W. E. Emley (*Trans. Amer. Cer. Soc.*, 19, 523, 1917). An illustrated account of an instrument satisfactorily used for measuring the plasticity of lime mortars, etc. It has not answered well for clays, but with certain suggested modifications it is believed the machine will give satisfactory readings with them also. The sample is placed on a plaster disc of known absorption, which revolves on a screw thread so as to force the material being tested upward against the surface of a conical disc whose side makes an angle of 10° with the horizontal. The spreading of the tested material (as pressure increases) is measured, and the friction is also measured.

DISCUSSION ON THE FINE GRINDING OF REFRACTORY MATERIALS BEFORE TESTING.—(*Trans. Amer. Cer. Soc.*, 19, 534, 1917). R. J. Montgomery mentioned that with a mixture of silica and clay corresponding in composition to the silica-alumina eutectic he had varied the softening point from cone 31 to cone 26½ by increasing the fineness of the ground material, and expressed the opinion that in prolonged use this mixture would slowly sinter and finally soften at cone 26½ regardless of the original coarseness. He suggests for serious consideration the determination of minimum refractoriness by grinding finely the samples of bricks and clay before testing, disregarding the time factor. He stated that silica bricks had been in constant use in coke ovens for nine years at an operating temperature of at least 2,600° F., and they and the cement used with them were still in very good condition.

Several others questioned the wisdom of grinding bricks before testing.

SLAG TEST FOR REFRACTORY BRICKS.—C. E. Nesbitt and M. L. Bell (*Proc. Amer. Soc. for Testing Materials*, 17, Part I, 314, 1917). Relates to a slag penetration test for bricks used in the iron and steel industry.

THE MICROSTRUCTURE OF SOME CLAYS IN RELATION TO THEIR PERIOD OF FIRING.—H. Ries and Y. Oinouye (*Trans. Amer. Inst. Min. Eng.*, p. 1,421, 1917). A paper dealing with some clays containing notable amounts of fusible impurities, and fired at temperatures not above 1,150° C.

The clays tested were moulded into 1-inch cubes and 3-inch bars, and one set was heated to 1,000° C. in 1½ hours, and held at that for 10 hours, a second set being heated to 1,150° C. in 3 hours and held for 10 hours. Samples were drawn at the end of the preheating period (when maximum temperature attained), and at hourly intervals thereafter, the test-pieces after removal from the furnace being buried in hot sand for slow cooling.

The two clays investigated were a brown residual clay from Ordovician shale, and greyish-white residual clay, presumably derived from Cambrian shale, both from Virginia.

The brown clay is soft and smooth, yellowish-brown when wet, and contains small fragments of unweathered shale. It grinds easily, and mixes with water to a fairly plastic mass. Under the microscope it shows minute flakes of hydromica and kaolinite, as well as small particles of iron oxide. Scattered angular fragments of quartz were also noticed. Biotite is rare.

The hydromica and kaolinite in the shale fragments were arranged parallel to the bedding planes of the material.

The white clay is very fine-grained and smooth, has a greasy feel, and high plasticity. Under the microscope were seen light brown aggregates of very minute kaolinite scales, angular fragments of colourless quartz, with small amounts of red iron oxide and occasional grains of brown biotite, yellow epidote, zircon, zoisite, and tourmaline.

The brown clay contained 51·08 per cent. silica, 22·05 alumina, 10·43 ferric oxide, no lime, 2·28 magnesia, 0·20 soda, 5·92 potash, 7·36 combined water, the total fluxes being 18·63. The white clay had 52·10 silica, 31·54 alumina, 2·38 ferric oxide, 0·10 lime, 0·58 magnesia, 0·27 soda, 1·89 potash, 10·89 water, the total fluxes being 5·22. They burned red and creamy-white respectively.

Details are given of the results of tests for fire-shrinkage, absorption, porosity, tensile strength (air-dried and after firing), and also the results of microscopic examination.

The results are thus summarized: When fusion begins in the mass the fine mineral grains are first affected and seem to change from a crystalline to an amorphous condition. There is a gradual change in the colour as the time of heating at one temperature continues. The hardness gradually increases on longer burning up to steel hardness. Absorption and porosity in each case run practically parallel, decreasing to a certain limit and then increasing again slightly. Absorption and porosity abruptly decrease when the mass approaches vitrification, as shown at 1,150° C. in the case of the white clay. The fire-shrinkage in both cases shows no change in the last 5 hours of continuous heating, while in the first 5 hours of heating at one temperature it shows a marked increase. The tensile strength seems to reach a maximum after 5 hours of continuous heating and then decreases. Microscopic study shows that the longer the burning the denser the texture up to a certain point, with change in colour in the brown clay. In both clays there is a gradual increase in the amount of isotropic material. Fusion of the hydromica and kaolinite proceed parallel with each other, but the former is more readily fusible. Corrosive action as seen in the quartz increases with the length of burning. Towards the end of the heating, at 1,150° C., pore spaces begin to develop, especially in the case of the brown clay.

STANDARDIZATION OF CHEMICAL STONEWARE.—H. Nielsen and J. R. Garrow (*Chemical Trade J.*, 62, 3, 23, 1917). It is stated that stoneware plant was first used in the chemical industry in this country, but was taken up by the Germans, who, however, imported clay from England. The authors suggest that this important industry can be recovered by careful organizing and standardizing in conjunction with research work and suitable plant. A chemical pottery in Germany has a large laboratory with a skilled research staff for controlling the manufacture in every way.

From numerous figures to hand the average ultimate tensile strength of high-class vitreous pottery seems to vary between 600 and 800 lb. per square inch. Some English stoneware almost equalled the best German material—namely, 842 lb.—but it will be safer to reckon with 600 lb., as this will cover almost any vitreous stoneware used in this country for acid-resisting pipes and other parts.

In a pipe under internal pressure, the force tending to burst it is the pressure per unit of area multiplied by the area of a section across the diameter. The resisting power is the thickness of wall multiplied by the length of the pipe multiplied by the ultimate strength. If p=pressure per unit of area, d=the internal diameter, l=the length of the piece, u=the ultimate tensile strength, and w=the wall thickness, then $p \times d \times l = u \times 2w \times l$. Hence $w = p \times d/2u$. Multiplying w by the safety factor gives the wall thickness required.

As to the highest pressure on a stoneware pipe, it is estimated that the pressure of a column of sulphuric acid in a Gaillard tower 90 feet high would be about 75 lb. per square inch, and this would probably be the maximum. Hence for a 2-inch pipe $w = 75 \times 2 \div 2 \times 600 = 0{\cdot}125$ inch. Allowing a safety margin of 4 gives a wall thickness of 0·5 inch.

As regards longitudinal stresses (owing to right angle bends, stop-cocks, etc.) the force p tending to fracture the pipe is the internal sectional area multiplied by the pressure per unit of area, or $p=\frac{1}{4}\pi d^2\times 75$. The part of the pipe resisting the fracture is the total area of the transverse section minus the internal area of the pipe, or $\frac{1}{4}\pi(d+2w)^2-\frac{1}{4}\pi d^2$. For a 2 in. internal diameter pipe with a wall thickness $w=0{\cdot}5$ in. the tensile stress u_1 is obtained from $u_1\times\frac{1}{4}\pi(d+2w)^2-d^2=\frac{1}{4}\pi d^2\times 75$, whence $u_1=60$ lb. per square inch. The ultimate tensile strength being 600 lb. per square inch, this gives a safety margin of $600\div 60=10$.

A table is given—and the corresponding curve plotted—showing the wall thickness corresponding to various diameters, etc. The internal diameters included are 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, and 4 inches, and the authors suggest that these standard pipes should be made in lengths of $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, 4, and 5 feet, in addition to the distance-pieces, which are very useful as making-up pieces between two flanges. Conical "buttressed" flanges are preferable to flat flanges. Bends, T-pieces, cross pieces, stop-cocks, and bib-cocks are considered separately, as well as iron armature and jointing material. A few notes on supports are added.

On p. 31 of the paper is a letter by Hugh Griffiths, who, while commending the main object of the article, criticises the basis of calculation. He states that the formula commonly employed in the design of thin cylinders such as boiler shells, which is the one derived by the authors, is not applicable when the walls are comparatively thick, for reasons well known to engineers. Several different methods are employed, which give varying results. Mr. Griffiths urges the importance, before agreeing on any final dimensions, of considering the value of the ultimate tensile strength of stoneware, and the most desirable factor of safety to adopt. The first essential is the standardization of material rather than of form, and there might be a British standard specification for chemical stoneware in the same way as for Portland cement. When this is done the work of Messrs. Nielsen and Garrow will be of greater value.

TEXTURE OF FIREBRICKS.—J. W. Mellor (Trans., 16, 40, 1917). A discussion of the important influence of size of grain, and of after-contraction and after-expansion, the effect of grog, etc.

SOME DISCOLORATIONS IN POTTERY AND BRICKS.—B. Moore and J. W. Mellor (Trans., 16, 58, 1917). A discussion of certain effects of oxidizing and reducing conditions during firing.

FIRING TEMPERATURE AND MICROSCOPIC APPEARANCE.—J. W. Mellor (Trans., 16, 71, 1917). A discussion of the question as to whether microstructure of fired mixtures afford reliable evidence of the firing temperature. It is concluded that time as well as temperature has to be taken into account.

DO FIRECLAYS CONTAIN HALLOYSITE OR CLAYITE?—J. W. Mellor (Trans., 16, 73, 1917). After reviewing the evidence afforded by microscopic appearance and heating curves, it is concluded that the dominant mineral in most fireclays, and in English ball clays, is clayite.

SPALLING OF MAGNESITE BRICKS.—J. W. Mellor (Trans., 16, 85, 1917). A discussion of the more important causes of this trouble.

A CURIOUS MINERAL IN A MAGNESITE BRICK.—H. B. Cronshaw (Trans., 16, 101, 1917). An account of crystalline particles tentatively regarded as being magnesioferrite.

TEMPERATURE MEASUREMENTS IN CLAY WORKS PRACTICE.—J. W. Cobb (Trans., 16, 118, 1917). A general survey of the various thermometers, pyrometers, etc., available for various purposes.

REFRACTORIES FOR STEEL FURNACES.—W. J. Brooke (Trans., 16, 205, 1917). A review of the subject from the consumer's point of view, with

special reference to silica and magnesite bricks. The author advocates the establishment of a research fund under the administration of The Ceramic Society, to which steel manufacturers and refractory brick makers should contribute. He contends that furnace managers would readily co-operate in testing new products if there be reasonable probability of improvement. A particularly interesting discussion follows the paper.

AFTER-CONTRACTION OR AFTER-EXPANSION OF FIREBRICKS IN OXIDIZING AND REDUCING ATMOSPHERES.—J. W. Mellor (Trans., 16, 268, 1917). A brief record of tests, the results of which show a general tendency for silica bricks to expand less in a reducing atmosphere than in an oxidizing atmosphere, and for fireclay bricks to contract more in a reducing than in an oxidizing atmosphere.

HOT AND COLD SIZES OF FIREBRICKS.—J. W. Mellor (Trans., 16, 270, 1917).—Tabulated results of tests, with a description of the apparatus and method of carrying out the tests. The thermal expansion was found to be associated with an after-contraction or after-expansion (if the brick were imperfectly burned).

BASIC REFRACTORIES USED IN SMELTING OPERATIONS.—A. Wasum.—(Trans., 16, 317, 1917). A somewhat full abstract of a German paper relating to the effects of some furnace conditions on lime, magnesia, and dolomite, with and without bonding material (in the form of clay, silica, calcium or magnesium phosphate, ferric oxide, etc.)

THE REFRACTORY PROPERTIES OF SILICA.—H. Le Chatelier and B. Bogitch (Trans., 17, 1, 10, 1918). A report of tests made on certain silica bricks, with a consideration of the structural features in relation to strength, proportion of fluxes, good formation of tridymite network, etc. The subsequent discussion was of unusual interest.

THE TESTING OF REFRACTORY MATERIALS.—J. W. Mellor (Trans., 17, 90, 1918). A discussion of the conditions of testing, with a reference to the necessity for the standardization of the methods of testing refractories. Reference is also made to the possibility (theoretically at all events) of manufacturing firebricks without kiln-firing.

EFFECT OF PRESSURE ON SUBSEQUENT CONTRACTION, ETC., OF TILES.—E. Watkin (Trans., 17, 111, 1918). A report on tests to ascertain the effect of pressure on subsequent contraction, tensile strength, and crazing.

RATE OF HYDRATION OF CALCINED DOLOMITE.—C. Edwards and A. Rigby (Trans., 17, 116, 1918). A note by Dr. Mellor on the decalcification of dolomite is appended.

THE INVERSIONS IN SILICA BRICKS.—A. Scott (Trans., 17, 137, 1918). Treats of the modifications of silica and micro-structure of silica bricks, etc.

ESTIMATION OF THE PROPORTIONS OF QUARTZ, TRIDYMITE, ETC., IN SILICA BRICKS.—A. Scott (Trans., 17, 188, 1918). A description of a comparatively rapid and accurate method by direct measurement.

THE REFRACTORY PROPERTIES OF MAGNESIA.—H. Le Chatelier and B. Bogitch (Trans., 17, 181, 184, 1918). A report of tests (for resistance to crushing, etc.) on various magnesia bricks and a chromite brick.

FUSED BAUXITE.—N. Lecesne (Trans., 17, 192, 1918). Description of a method for manufacturing refractory materials with fused bauxite.

COMPRESSIVE STRENGTH OF SOME FIREBRICKS.—S. Kanashima (*J. Chem. Industry*, Tokio, 19, 1,162, 1916). Different mixtures of three materials were used, viz.: (1) "Kibushi," a fireclay melting at cone 32; (2) grog (chamotte) from this clay and others; (3) "Roseki," a variety of galmatolite (hydrated silicate of magnesia usually containing more or less

potash) used for making fireclay wares in Japan. The trials were burned to cone 12. "Roseki" gave greater compressive strength than grog. The weight ranged from 1·55 to 2·10 g. per c.c., and the strength increased with the weight. Water absorption ranged from 9 to 22 per cent., increase being accompanied by decrease in strength. The compressive strength was greater when saturated than when dry. Firing contraction ranged from 2·5 to 1·7 per cent. in volume, but apparently showed no relation to the strength.

ACTION OF HEAT ON CLAY MARL.—C. Cirielli (*Bol. Min. Agr., Indus. e Com.*, Rome, Ser., B 14, 91, 1915, I; *Expt. Sta. Rec.*, 35, 119, 1915). Clay marl was progressively heated from 700° to 800° in an electric furnace. The author concludes that the water of hydration is completely driven off by heating to 700°, and that the decomposition of carbonates and expulsion of CO_2 proceeds rapidly at 800°. Beyond 800° it was found that the density tended to increase with progressive heating.

CLAY SUSPENSIONS.—A. Müntz and H. Gaudechon (*Vie. Agr. et Rurale*, 5, 380, 1915; *Expt. Sta. Rec.*, 35, 211, 1915). Clay suspensions of the same type but of three different concentrations were studied, each suspension being siphoned into four fractions after 48 hours. The amount of suspended matter deposited increased with concentration of the suspension, whilst the difference between fractions increased as the concentration decreased. The clay suspension disappeared most rapidly in the uppermost fraction of the weakest concentration. Temperature did not materially influence deposition. In the successive fractions it was found that the rate of deposition (expressed in arbitrary units) ranged from 100 in the first hour to 1 in the 144th hour. In studies with a single clay and four different clays, to determine the influence of gravity and of an electric field on deposition, the results agreed with the results of work previously reported.

HEAT-INSULATING MATERIALS.—(*Power*, 45, 593, 1917). A report on tests by Sargent and Lundy, of Chicago. The tests were applied to materials made or cut to the size of standard bricks. Thermometer holes were cut in the bricks, and, after placing the thermometers in position, the holes were packed with powder of the same material as the brick. The furnace was built of Osceola firebrick, the base of slabs 20 in. × 12 in. × 4 in., the housing for the gas torch having sides 1¼ in. thick, and the roof being of standard bricks.

All samples of the materials were carefully bedded into position, and equally spaced and insulated from one another. The temperature of the source of heat was measured by means of the thermocouple.

All the thermometers having been read, the gasoline torch was placed in position, and readings were taken every 15 or 30 minutes. The gasoline torch did not possess much flexibility, and was difficult to regulate satisfactorily. Curves were plotted showing the rate of increase of the temperatures at the different thermometer positions. When equilibrium was established (at the time T) a cross-plot was made, giving the temperature gradient, which was considered to be a measure of the insulating value of the material. The results were shown by means of interpolated curves showing the behaviour of each material, but the differences exhibited in this way between firebricks and insulating bricks was not great enough.

It was therefore decided to adopt a method based on measurement of the actual quantity of heat passing through the material under test. This was done by building a furnace of the various materials, cut to the dimensions of standard bricks, and carefully laid up with small joints. These furnaces were heated by means of an electrical heater made of arc-lamp resistance coils and arranged to evenly distribute the heat over the inside. The electrical input to the heater was converted into B.T.U. by multiplying the watt hours consumed by 3·412. If the electrical input is constant, the temperature will rise in the furnace until the temperature difference between the inside and outside is sufficient to cause the heat generated to be dissipated at an equal rate; then equilibrium is established. On establishing equilibrium, readings were taken

of the electrical energy and the temperature of the inside and the outside of the furnace. By varying the electrical energy a curve can be drawn between the temperature difference of the inside and the outside of the furnace, and the B.T.U. radiated per hour. Such curves show the great advantage from a thermal point of view of the insulating materials over the ordinary firebrick. It is seen from the shape of these curves that the materials have not such a good insulating value at high temperatures as at low ones. This variation in insulating value with the temperature is expressed—in "thermal Ohms"—by dividing the temperature difference by the B.T.U. radiated per hour. These values for the materials, having been calculated and plotted out, show practically straight lines, except for magnesia and a combination of sigur and magnesia. With this latter material the "thermal resistance" decreases directly as the temperature difference. Magnesia falls off rapidly at the high temperatures because a chemical change takes place and it becomes disintegrated. Such disintegration takes place in time even at low temperatures, as in magnesia coverings for steam pipes. The sigur-magnesia furnace was made up of half thickness of sigur and half of magnesia, in the expectation that the sigur might protect the magnesia so that its extra insulating qualities might be utilized; but the combination has the same characteristics as the plain magnesia, though not so pronounced.

To use the figures thus obtained for finding the equivalent thickness of material required to give equal insulation (or equal thermal resistance in each case) the laws of thermal resistance needed experimental demonstration. Furnaces of half and twice the thickness of the original furnace were built and tested, and the results proved that the thermal insulation is directly proportional to the thickness.

The material of highest thermal resistance is the raw Kieselguhr product (trade name, Sil-o-cel). At 2,000° F. one thickness of Sil-o-cel equals:

6·5	thicknesses of	Osceola firebrick,
1·85	,,	Diddier insulating brick,
1·65	,,	Sigur-magnesite insulating brick,
1·35	,,	Sigur insulating brick,
1·20	,,	Nonpareil insulating brick.

The following data were also obtained from tests:

	Weight of water Absorbed	Porosity per cent.	Weight in lbs. per cub. ft.	Apparent Density	Real Density
Osceola ...	9·3 per cent.	19·3	129·0	2·06	2·55
Sigur	40·0 ,,	55·6	49·4	·79	1·78
Sil-o-cel ...	166·0 ,,	79·4	29·9	·478	2·29
Diddier ...	147·0 ,,	67·8	28·7	·459	1·42
Magnesia ...	327·0 ,,	82·8	15·8	·253	1·47
Nonpareil ...	96·0 ,,	44·5	29·1	·467	·84

High porosity appears to be an essential property of a thermal insulating material.

CRUSHING TESTS OF HEAT-INSULATING MATERIALS.

	Before heating lbs. per sq. in.	After heating lbs. per sq. in.
Sigur	357·6	339·7
Sil-o-cel, with strata	171·6	168·0
,, against strata ...	404·0	379·0
,, average	288	274·0
Magnesia	144	Crumble easily
Diddier	39·3	Crumble easily
Nonpareil	183·0	168·0

Furnaces of sil-o-cel and sigur were built and run at 1,200° F. for over six months continually, with no change in the insulating properties and with no damage to the materials themselves.

MOULDING SANDS, FACING SANDS, AND BLACKINGS.—S. G. Smith (*The Foundry Trade Journal*, pp. 476—9, 1917). Notes for iron foundry

apprentices. The chief requirements for an iron foundry moulding sand are silica, clay, and water. In a common moulding sand, coal dust and blacking are used to protect the silicates and oxides of the sand (which are fusible at a temperature lower than that required to melt iron for castings) and enable them to endure such heating as is involved as in the slow cooling of thick castings. The clayey matter present in moulding sands acts as a plastic bond when a suitable amount of moisture is present. The proper amount of moisture is ascertained by experience, and works out at 5 to 7 per cent. of uncombined water.

If no artificial binder has been added, a strong sand (containing relatively large amount of clay) must be used for thick castings, and a weak sand (with relatively small amount of clay) should be used for light, thin castings, while medium sand is to be used for medium-thickness castings.

The function of a facing sand is to give the casting a clean skin, *i.e.*, the sand should strip easily from the casting. The amount of sand to form the face part of a mould in light castings need never exceed $\frac{1}{4}$ inch in thickness. As the castings become heavier and stronger the thickness may run to $\frac{1}{2}$ inch, and in the thickest castings (up to 3 or 4 feet thick) an inch of facing sand is as good as 12 inches. For thick and very thick castings opening material (chiefly horse manure) is necessary to give the stronger and tougher facing sand the required porosity. Coal dust is mixed with the facing sand to give, not porosity, but a protecting film or thin covering deposited on the surface of the mould, and so prevents the oxides and fusible silicates of the sand from being melted by the hot iron. The addition of dry blacking to the facing sand will answer the same purpose by giving a clean skin to the casting; but the proportion of blacking required is much larger than that of coal dust. In the absence of coal dust a fairly thick casting in green sand would have a dirty white or grey colour, with a skin of partly-fused weak silicates or oxides of the sand, the proper skin of the iron being beneath it.

Scabbing arises, if the facing sand or the ordinary ramming floor sand is too wet, when the molten iron touches the sand, owing to the too rapid generation of hydrogen or steam, quite rough lumps being left on the casting.

Green sand cores for small thin castings should be made of weak sands, the sands becoming stronger as the castings become thicker and heavier. Dry sand cores, whether large or small, are as a rule made better and firmer when the sand has been milled with plenty of opening material (such as manure, fine sawdust, etc.) ground in and well mixed together; this will make the sand quite open and porous, and more easily cleaned from the casting when being dressed.

Loam is made of milled moulding sand, ground with water to give plasticity, manure and other opening material to give porosity, and cowhair for cohesion. These materials are milled to a stiff or sloppy consistency according to the work required. If the loam is required for bricking only, it may be coarse and porous, but if required for finishing (that is, the last striking course) it must be finely ground.

A weak or strong sand may greatly increase in bond by being milled in a roller mill, but excessive grinding can make the sand too dense for moulding purposes. A sharp sand (seashore or beach sand) will acquire neither bond nor plasticity by prolonged grinding.

The most intricate cores, large and small, are now made from beach or sea sand with oil as an artificial binder, from half to one pint of oil being used with one bucketful of sea sand, and the only other addition being about 5 per cent. of water. Such cores, when properly made and dried, are hard, need minimum of support from core rods and irons, and have maximum porosity. The drying of these cores needs care.

Blackings include charcoal, plumbago, and blacklead. Charcoal is a light blacking chiefly used for mixing with other blackings, sometimes with sand, and often for covering molten iron in the large ladle to keep the surface from crusting or solidifying. Plumbago blacking makes an excellent blacking for light or heavy moulds. Blacklead is a graphite carbon with shining metallic lustre. It is too heavy to be used alone for a blackwash, but is added

in small quantities to inferior blackings. It is often used dry to dust moulds to give the castings a bright clean appearance.

For black-washing moulds all blacking must be mixed with claywash, which is common clay mixed with water. This claywash is mixed strong (or thick) for heavy work, weak (or thin) for light work. The mixing is done in an iron tank or "bosh," and the usual rule-of-thumb method is to judge its suitability in the handful. The claywash acts as a binder to the blacking, and a clean bluish skin is left on the casting.

Blackwash is only used for dry-sand work and loam work, both moulds and cores. If it peels when dried the claywash is too strong, and if the casting shows excessive erosion and does not give a clean skin the claywash or the blacking has been too weak. The wet blacking is sometimes washed over with water, but this removes the blacking. Dry blacking dusted on green-sand moulds should be sleeked in, not blown off again with the bellows.

If enough blacklead be rubbed or sleeked on a green-sand mould coal dust may almost be absent in the sand.

The following are a few mixtures of facing sands used in a general foundry: (1) *For very light green-sand machine-made castings.*—2 barrows of fine new sand, 4 barrows of good floor sand, 3 buckets of coal dust; mixed together and passed through a rotary mixer. (2) *For light green-sand work.*—2 barrows of new sand, 3 barrows of old sand, 3 buckets of coal dust, 1 bucket of dried manure (not milled). (3) *For medium green or skin-dried work.*—16 shovels of new sand, 4 shovels of old sand, 1 bucket of coal dust, 2 shovels of dried manure, milled for 5 minutes. (4) *For dry-sand heavy work.*—Half new sand, half old sand, 4 shovels of manure, milled for 10 minutes. *Core sand for heavy work.*—All new sand, with 3 shovels of manure, milled 15 minutes. *Core sand for light and medium work.*—Half new sand, half old sand, 3 shovels of manure, milled for 15 minutes.

PREPARING A CUPOLA.—A. R. B. (*The Foundry Trade Journal*, p. 480, 1917). Notes relating particularly to the making up of the bottom of a cupola and the material to be used therefor. From 2 of the 4 cupolas installed it is common practice to get 120 tons of metal per day if necessary. The average from one cupola for the year is about 50 tons per working day. The cupolas range in size from 2½ to 5 feet inside the brick lining. All have hinged bottoms for dropping, the smallest one being hung on the one side, and the others hung on hinges on both sides so that when dropped the bottom opens in the middle. The pressure of the blast used is about 12 to 14 oz., and the wind enters the furnaces from the wind belt by 4 tuyeres in the smallest furnace, by 6 tuyeres in the second size, and by 10 in each of the two largest. These cupolas have only one main blast pipe, admitting air to the wind belt in one place only. (Many cupolas have air admitted to the wind belt on two opposite sides, but this the author considers immaterial if the desired volume gets into the cupola). The wind is prevented from going into the cupolas not in use by means of a valve attached to the branch pipe leading from the main wind pipe to the wind belt. All the tuyeres are round at the hole admitting the air to the cupola, and as regards position in the wind belt they are staggered.

The lowest tuyeres in the small cupola are 10 in. from the highest part of the bottom when made up, and in the case of the largest cupola 14 in. All the cupolas are brick lined up to 9 in. thick, the bricks being made to suit each size of cupola; the lining is left out where the tuyeres are and where the tapping hole is to be made. The practice is to have a hole about 6 in. square, in which after every blow a new tapping hole is made. The method is to make a tapered hole from the front of the cupola to about the centre of the 9 in. wall, where the narrowed hole is then enlarged again, making a tapered hole again with the largest side in the inside of the cupola. The size of the hole is governed by the amount of molten metal the cupola can deliver, so that the charging of the cupola, the melting and the flow of the metal into the ladles, are not out of balance. This can only be determined by the men who have to work the cupola, for each one has its peculiarities, and no hard and fast rule can be laid down. Speaking generally, the tapping holes of the

two smaller cupolas are $\frac{5}{8}$ in. in the smallest part, tapering up to 3 in. on both inside and outside of the cupola. These cupolas run 5 and 8 tons per hour respectively. In the two largest cupolas, the smallest part of the tapping tunnel ranges from $\frac{3}{4}$ in. to $\frac{7}{8}$ in., according to whether a long tap is running or not. If running for a casting of, say, 30 or 40 tons, the hole is made slightly larger, right up to the capacity of its melting powers, so that it delivers the metal as fast as it can be charged. The whole of the tapping tunnel, the hole and the tapping trough are lined and made up with fresh ganister after every blow on the larger cupolas, and the hole and tunnel on the smaller ones, the trough on the smaller ones lasting some considerable time with slight patching.

The cupola bottom, small or large, is made up with the ordinary black floor sand. The sides of the cupola, where burned away in the melting zone, are patched with ganister, the bottom being then closed and made secure. The black sand is then thrown in through the back door of the cupola by one man, while another man inside treads it solid, and rams round the side close to the brick lining with a pin rammer to make it tight and secure. The sand is then shaped to form a graduated slope from all points towards the bottom of the tapered tapping tunnel, and then flat-rammed quite solid. The bottom bed is thus made hard close to the wall of the cupola and on the top surface of the bed. The lower part of the bed being only trodden with the man's feet, is rendered slightly porous, so that the gases generated, as in a mould, get out through the cracks and joints of the drop bottom. The sand bottom gets very open with constant use, the sand being used over and over again, and getting mixed with it much small coke and slag. After the bottom is dropped at the finish of the blow, the heap of sand, coke and slag is raked and spread out, while water is played on it with a hose-pipe. When there is no risk of it burning, it is left till morning, and is then picked over and sifted with $\frac{1}{2}$ in. mesh sieve. The heap of rough and open sand thus obtained is what the bottom is always made up with. The only replenishing it gets is from the fresh black floor sand that is used when making up the back door after the fire is well alight. This is done every time the cupola is used, and thus keeps the bottom sand always of about the same consistency.

The depth of sand forming the bottom ranges from 6 in. in front (near tapping hole) to 8 in. at the back (nearest door), in the smallest cupola, to 8 in. and 10 in. respectively in the largest, the slope being 2 in. in each case.

The tapping hole must always be thoroughly dried (usually with a hot bar) to avoid the serious risk of a set tap hole. It is better to light the fire early to get the bottom well dried.

TESTING FIREBRICKS.—(*The Foundry Trade Journal*, p. 486, 1917). Report of a paper read before the American Society for Testing Materials by C. E. Nesbitt and M. L. Bell. The tests applied included impact test, abrasion test, spalling test, slagging test, and compression test.

Impact Test.—This was applied by dropping a $2\frac{1}{2}$ in. steel ball from various heights on a brick heated to the working temperature. A brick thus tested at 260° C. was 20 per cent. weaker than a similar brick at 20° C., and at 540° C. was 40 per cent. weaker.

Abrasion Test.—This was conducted, with the brick cold, by means of an emery wheel. Tests showed that there is sometimes 10 to 20 times the abrasion at one end as at the other end of a brick.

Spalling Test.—The brick was placed in the wall of the furnace, exposing only one end, which was subjected to a temperature of 1,350° C. for one hour. It was then cooled in water, which was found to be three times as effective as cooling in air. Amount of spalling is reported as percentage loss in weight.

Slagging Test.—A cavity was drilled in the brick and filled with slag. The brick was cut so as to expose a cross-section of the slag pocket, and the area of the slag penetration exposed was measured by a planimeter.

Compression Test.—A modified Brinnell ball test was applied by heating a brick to 1,350° C., removing it from the furnace and forcing a $2\frac{1}{2}$ in. steel ball into it under a pressure of 1,600 lb.

Results of Tests.—It was found that the firebricks tended to group themselves according to density. Other qualities being the same, the bricks of high density had generally the best qualities—least abrasion, least compression and good resistance to slag. Spalling was slightly increased, but not dangerously so if the bricks were not overburned. Specific gravity, obtained by weighing and measuring the brick, was the measure of density. Various makes of bricks had characteristic values for apparent specific gravity, and the method of manufacture influenced the density.

To determine the effect of pressure and moisture in producing a dense brick, a standard fireclay mixture was used in which the moisture varied from 4 to 12 per cent. All bricks were pressed at 2,000 lb. per square inch, and then burned in a regular kiln. The results of these tests were as follows:

	Percentage of moisture					
	4	6	8	8·5	10	12
Compression ...	0·49 in.	0·44 in.	0·43 in.	0·51 in.	0·53 in.	0·57 in.
Expansion ...	0·64 in.	0·64 in.	0·45 in.	0·45 in.	0·49 in.	0·50 in.
Impact ...	18 in.	33 in.	35 in.	35 in.	31 in.	30 in.
Abrasion ...	0·024 in.	0·008 in.	0·012 in.	0·016 in.	0·028 in.	0·020 in.

		4	6	8
Slag penetration	Blast furnace slag...	0·375 sq. in.	0·30 sq. in.	0·21 sq. in.
	Heating furnace slag	1·00 sq. in.	0·375 sq. in.	0·30 sq. in.
	Open hearth slag ...	0·81 sq. in.	0·48 sq. in.	0·60 sq. in.
Apparent specific gravity		2·11	2·17	2·19

		8·5	10	12
Slag penetration	Blast furnace slag...	0·30 sq. in.	0·43 sq. in.	0·375 sq. in.
	Heating furnace slag	0·42 sq. in.	0·42 sq. in.	1·27 sq. in.
	Open hearth slag ...	0·67 sq. in.	0·67 sq. in.	0·73 sq. in.
Apparent specific gravity		2·16	2·10	2·06

Power-pressing a brick during manufacture up to 1,500 lb. per square inch. was found to materially improve the quality of most firebricks. Beyond that figure little improvement was made.

The following table compares tests on a high-pressure, low-moisture brick, and a hand-made, repressed, ordinary-moisture brick, both being of the same mixture.

Comparative Tests of (a) High-Pressure, Low-Moisture Brick, and (b) Hand-made, Repressed, Ordinary-Moisture Brick.

		a (Pressure of 1,500 lb. per sq. in. Moisture 7 per cent.)	*b*
Compression at 1,350° C.		0·29 in.	0·55 in.
Expansion per foot length at 1,350° C.		0·062 in.	0·059 in.
Impact at 260° C. (height of drop) ...		45 in.	28 in.
Abrasion at 1,350° C. in 5 minutes ...		0·02 in.	0·04 in.
Spalling, loss		9·4 per cent.	10·6 per cent.
Slag penetration	Blast furnace slag ...	0·27 sq. in.	0·56 sq. in.
	Heating furnace slag	0·26 sq. in.	0·67 sq. in.

The methods above described have been developed mainly with reference to the brick used in iron and steel plants.

SILICA REFRACTORIES.—(*The Foundry Trade Journal*, pp. 487—8, 1917). Report of a paper read at a meeting of the American Institute of Mining Engineers, by J. S. McDowell (of the Harbison-Walker Refractories Co., Pittsburgh). The investigation was a continuation of one begun by Mr. Kenneth Seaver (chief engineer of the same company). Three lots of silica bricks, about 9 in. × 4½ in. × 2½ in., were made up of "regular," "medium," and "fine grind" respectively. The regular grind specimens were made by the usual method for 9 in. bricks; those of medium grind were given the grind used for silica shapes and pounded into loose side moulds, as silica shapes are treated. The material used for the fine grind was screened through an 8-mesh hand screen, returned to the pan and reground long enough to add

and mix lime thoroughly; the bricks were pounded into loose-side moulds. Screen analyses are shown in the following table.

SCREEN ANALYSES OF TEST BRICKS.

Grind	Screen numbers in meshes per linear inch					
	Percentage held on					Through
	8	16	20	30	40	40
Regular	15·3	13·4	4·6	5·4	4·8	56·5
Medium or Shape ...	10·2	13·1	2·2	5·0	4·7	64·8
Fine	—	14.3	4·1	6·5	4·1	71·0

The bricks were burned under the ordinary conditions of manufacture at three positions (*A*, *B*, and *C*) in the kiln. The bricks were burned a number of times, being under fire about ten days each time, the temperatures attained varying from 1,390 to 1,450° C. (measured by cones).

In the transverse tests for strength, the modulus of rupture (R) was calculated from $R=3Wl/2bd^2$, in which W=load (in pounds) at which failure occurred, l, b, and d (all in inches), the distance between supports, breadth and depth of specimen respectively. The crushing strength was obtained by dividing the crushing load (in pounds) by the mean area (in square inches) of the two surfaces of the brick. The average of three tests gave a mean modulus of rupture of 920 and 1,050 in two sets, and mean compressive strength (from half-brick crushed flat) of 2,680 and 4,780 in two sets.

Uniformity of strength of a given lot of bricks diminishes with repeated burning, slightly in compression, considerably in cross-breaking. The most uniform bricks are those of regular grind; fine-grind bricks are fairly uniform in crushing, but far from uniform in cross-breaking strength. The figures indicated that the medium grind brick is the most satisfactory in point of strength, the regular grind least so. The compressive strength of the medium grind is somewhat lower than that of the fine grind, but its cross-breaking strength is greater and it is a much more uniform material. In cross-breaking, the fine-grind shows little if any advantage over the regular grind, for while its mean strength is high it lacks uniformity; in compression it is far stronger than the regular grind.

There is in all cases an advantage in burning the bricks a second time; for the medium and fine-grinds a third burn is usually harmful, decreasing the cross-breaking strength considerably and increasing the compressive strength very slightly. Bricks of regular grind increase in strength on each burn up to the third, slightly in compression, considerably in cross-breaking. The alternate expansions and contractions incurred in repeated burning may tend to cause the formation of minute cracks in the bricks and to have an unfavourable effect upon their strength. For that reason it is probable that stronger bricks would be produced by maintaining the maximum temperature a greater length of time during a single burn than by resorting to repeated burning. The effect of repeated burning on the constitution of bricks of regular grind, burned several times, is shown by the following analyses:

Mineral	Number of burns			
	1	3	4	6
	Vol. %	Vol. %	Vol. %	Vol. %
Quartz (+silicates) ...	25	16	12	14
Cristobalite ...	71	64	58	42
Tridymite ...	4	20	30	44

It is evident that in the first burn the larger part of the quartz is transformed into cristobalite, and that on repeated burning the remaining quartz is very slowly transformed. The cristobalite at first very slowly, and later more rapidly, inverts to tridymite. Time and burning temperature appear to be the controlling factors. Bricks burned once at 1,410° to 1,430° C. show essentially the same amount of transformation; those burned at 1,390° C. show considerably less. The effect of variations in grind is comparatively slight.

ELASTICITY AND STRENGTH OF STONEWARE AND PORCELAIN.—J. E. Boyd (*Amer. Soc. Mech. Engrs.*, p. 795, 1918). An illustrated account of a series of tension and compression tests, and also bending on specified samples. The results are tabulated and also plotted in curves, and from these results the following conclusions are drawn: (*a*) The modulus of elasticity of stoneware and porcelain is practically the same in tension and compression. Its value may be obtained conveniently by a bending test. (*b*) The modulus of elasticity of porcelain is about 10,000,000. The modulus of elasticity of stoneware ranges from 6,000,000 to 9,000,000, depending on the material. (*c*) The compressive strength of porcelain and high grade stoneware in a column 16 in. long and 1 in. in diameter is about 20,000 lb. per square inch. The stress-strain diagram is practically straight up to 7,000 lb. per square inch. (*d*) The tensile strength of porcelain is above 3,000 lb. per square inch. The diagram is a straight line up to this stress. The tensile strength of stoneware ranges from above 1,100 to 2,200 lb. per square inch. The stoneware of the greater modulus has the greater strength.

The tests failed to develop the full tensile strength of the material. Judging from the bending tests and the form of the diagrams, it is probable that the real tensile strength is about twice as great as the figures here given. (The porcelain samples were obtained from the General Electric Co., and the stoneware samples from the Keasbey Stoneware Works).

In the course of discussion, Mr. L. E. Barringer remarked that as regards the mechanical strength of porcelain the most consistent property is the resistance to crushing, and the most erratic and unsatisfactory is the toughness or resistance to the sudden shock of impact or vibration. He suggested that 1,500 lb. per square inch might be taken as a working figure for tensile strength, since with special clips, etc., it only showed 3,000 lb.

WATER-GLASS AND ALKALI-SILICATES.—W. Pukall (*Berichte der Deutschen Chemischen Gesellschaft*, 49, 397, 1916). When silica is melted with the requisite quantity of potassium carbonate (or even with excess of latter), potassium metasilicate, K_2SiO_3, is formed, for according to H. Rose one molecule silica can expel no more than one molecule carbon dioxide. The glassy mass attracts water from the air and deliquesces, as Helmont observed in 1640.

Fuchs in 1818 discovered potassium tetrasilicate, $K_2Si_4O_9$, which he obtained by melting together 45 quartz, 30 potash, and 3 parts of powdered wood charcoal. This compound does not deliquesce in air, but dissolves in water, hence he designated it as water-glass. Fuchs in like manner obtained sodium tetrasilicate, $Na_2Si_4O_9$, or soda water-glass (by heating 45 quartz with 23 anhydrous sodium carbonate and 3 parts of powdered wood charcoal), as a transparent yellowish or brownish glassy mass, which dissolves as a powder in boiling water to a thick liquid.

With excess of sodium carbonate on the other hand the trisilicate, $Na_8Si_3O_{10}$, is always formed, and by melting equal molecules, sodium metasilicate, which according to Yorke dissolves clear in water. Evaporated over sulphuric acid, crystals separate from the solution of the same composition with 7 molecules water. Petersen reports another hydrate of the same compound with 5 molecules of water appearing in large monoclinic crystals. Nothing is reported of the crystallizing power of the other alkali silicates mentioned.

More recently Kohlrausch concluded from the conductivity of sodium silicate solutions that this salt in solutions is completely decomposed hydroly-

tically, producing a solution of soda lye and colloidal silica. Kahlenberg and Lincoln arrived at the same result from freezing point determinations.

Jordis and Kanter showed that sodium silicate is not decomposed by dialysis into NaOH and H_2SiO_3, but into $2NaOH+Na_2Si_2O_5$, aq., which goes through the membrane and so is a crystalloid. Later, Jordis referred to a suitable method for extraction (from pure sodium water-glass) of crystallized sodium metasilicate with 6—10 molecules water of crystallization. If this latter be mixed with sufficient NaOH to produce the proportion $3Na:1SiO_2$, the condition for separation of crystallized sodium metasilicate is given. The salt is obtained pure by re-crystallizing from 1N—NaOH and washing with 50 per cent. alcohol. A crystallized potassium silicate was not obtained. Jordis later studied the double decompositions between sodium metasilicate and salts of heavy metals, starting from the simply producible salt $Na_2SiO_3+8H_2O$. Jordis and Hennis found that solutions of $Na_2Si_2O_5$ or $2Na_2SiO_3$, which are analytically identical, behave exactly like solutions of Na_2SiO_3.

If water-glass or alkali-silicate solution of sufficient concentration be left to stand several months loosely closed or open to the air, and then decomposed with HCl, chlorine gas is evolved with HCl. Jordis from this concludes the possibility of persilicates. Jordis and Erdenbrecher produced a series of sodium silicates with nH_2O and came to the conclusion that hydrates with less than $6H_2O$ are still uncertain, but are likely. Rhombic crystals arise most readily in connection with the salt with $9H_2O$, and particularly well from alkaline solution. The salt with $6H_2O$ forms monoclinic crystals. From the mother liquor was then obtained after two days rhombs with $9H_2O$. According to Kohlrausch the chief ingredient of dissolved water-glass is sodium disilicate, $Na_2Si_2O_5$.

Vesterberg describes as a well-defined sodium metasilicate the sodium metasilicate enneahydrate produced by him from soda water-glass, while Pukall describes not only a hydrate of his earlier mentioned anhydrous crystallized sodium metasilicate, crystallizing in monoclinic prisms or tables, but also a simple method for the production of anhydrous potassium and sodium disilicates, $K_2Si_2O_5$ and $Na_2Si_2O_5$, in any quantity and in crystallized condition. Morey and Fenner obtained a crystallized potassium hydrogen disilicate, $K_2O.H_2O.4SiO_2=2KHSi_2O_5$.

Pukall obtained hydrated alkali alumino-silicates in a hermetically sealed glass tube heated by a water bath for a long time.

The present investigation was made with mixtures of alkali bicarbonates with very finely ground Hohenbocka glass sand. Both sand and bicarbonate were passed through a 9,200-mesh sieve, the materials being most intimately mixed, and melted to clear glasses at about 1,050° C. The mixtures ranged from 1:1 to 6:1, using 1, 2, 3, 4, 5, 6 molecular proportions of silica respectively to 1 of K_2O or Na_2O.

The refractoriness increased with increase of silica. In the product with $6SiO_2.K_2O$ only slight turbidity was shown, in portions broken through with bubbles; the same was the case with $5SiO_2.Na_2O$, while $6SiO_2.Na_2O$ was only strongly sintered. All the glasses were coarsely powdered, melted a second time, the easily fusible ones at the same melting heat, the rest at about 1,270° (cone 7). The $6SiO_2.K_2O$ was now clear, the $6SiO_2.Na_2O$ formed a white, very hard, sugar-like mass, while $5SiO_2.Na_2O$ seemed completely melted but yet not entirely clear. The powder of $SiO_2.K_2O$ strongly absorbed water from the air, glass particles up to the size of lentils being dissolved within a short period. The powder $2SiO_2.K_2O$ showed this effect also, though not so pronounced. This power of attracting water is continued in the potash series up to $5SiO_2.K_2O$. In the sodium series only the compound $SiO_2.Na_2O$ thus absorbs water. Water which was only a short time in contact with the powder showed in all cases strong alkaline action. All the potash series except $6SiO_2.K_2O$, as well as $SiO_2.Na_2O$ and $2SiO_2.Na_2O$ dissolve entirely in cold water. The product $2SiO_2.K_2O$ provides a somewhat thick liquid, those with $3SiO_2$ and $4SiO_2$ are remarkably thin for the same content, that with $5SiO_2$ more viscous and also takes longer to dissolve. From the solution with $3SiO_2.K_2O$ flakes separate after some time, but that with $4SiO_2.K_2O$ remains

clear. In the sodium series, that with $3SiO_2.Na_2O$ leaves a small residue, which is considerably increased in those with $4SiO_2$, $5SiO_2$, and $6SiO_2$. Heating the solution water scarcely produces any change. In all cases 2 g. of the substance was dissolved in 5 c.c. of water.

Exact results obtained in further investigations of the solutions are given in a table.

The chief points are included in the following statements:

1. Potassium and sodium silicate melts behave nearly alike respecting their solubility in water, the potassium compounds showing a somewhat greater solubility and speed of solution than corresponding sodium compounds.

2. Solubility gradually decreases with increasing silica content.

3. The melts do not go into solution according to their composition, but they decompose especially with regard to the more highly siliceous members, into compounds with lower silica content. In the potash series are found $4SiO_2.K_2O$, aq. $3SiO_2.K_2O$, aq., further $2SiO_2.K_2O$, aq., $SiO_2.K_2O$, aq., and $0{\cdot}5SiO_2.K_2O$, aq., or $SiO_2.2K_2O$, aq. In the soda series this phenomenon is repeated, with the difference that the member $4SiO_2.Na_2O$, aq. apparently is wanting altogether, $3SiO_2.Na_2O$, aq. appears in transitory manner $2SiO_2.Na_2O$, aq. is predominant, and moreover also the member SiO_2Na_2O, aq. and quite subordinately $SiO_2.2Na_2O$ appear. By water is thus caused apparently a vast decomposition of the melts or they are not homogeneous, but mixtures of different compounds, in which with the more highly silicated members silicic acid is found in solution. The result permits at the same time an interesting insight into the composition of technical water-glass solutions, in which some of the compounds described have actually been found.

4. Since the bodies mentioned so easily permeated the porous cell wall, which otherwise is not permeable for colloid substances, they can be regarded quite as crystalloids. Those salts to which the cell wall opposed the smallest obstacle may possess this property most decidedly.

5. It is very noteworthy that in most cases and in both series the silica content of the compounds increases at first by progressive leaching out, then gradually decreases so strongly in favour of the alkali content that it sinks far below the proportion 1 : 1. Jordis and Kanter made a similar observation in the leaching out of alkaline earth silicates with water.

The residues in the porous tubes gave quite the impression of unaltered glass powder, although the silica in them had probably increased considerably. An analysis was made only in the case of the melt $6SiO_2.Na_2O$, which gave $97{\cdot}15SiO_2$, $0{\cdot}72Na_2O$, 2·13 loss on ignition, and showed that the leaching out was far advanced.

Comparison of results indicates that a larger quantity of water causes greater decomposition.

For the action of water at higher temperatures (and under steam pressure) tests were made with 15—45 g. of the silicates in closed tubes 30 cms. long and 25 mm. external diameter. The tubes were so little attacked that they could be used repeatedly. The quantity of water mixed with the powders was barely sufficient with the lower members, but was somewhat more copious with the more highly silicated glasses. It fluctuated between 0·2—0·3 c.c. to 1 grm. of the substance, and the heating fluctuated between 180° and 210° for those rich in alkali and those poor in alkali respectively.,

Potash Series. Melt 1 : $SiO_2.K_2O$. Of the powdered substances 4 grm. is used with 7 drops (0·55 c.c.) water, and heated 6½ hours at 180—195°. The product is a steel-blue grey, thoroughly crystalline mass, which becomes more and more adhesive and finally deliquesces. Under the microscope, immersed in absolute alcohol, it shows stout flat doubly refracting prisms, which remind one of the hydrate of the corresponding sodium compound, $Na_2SiO_3+6H_2O$. In water the compound dissolved uncommonly easily and clear. By standing in an open tube the solution had decomposed in about two weeks through separation of gelatinous silicic acid. A sample of the crystallized substance dried for a long time over concentrated sulphuric acid gave 17·31 per cent. loss on ignition, which corresponds to the formula $K_2SiO_3+1{\cdot}81H_2O$.

Melt 2. $2SiO_2.K_2O$. The easily producible, anhydrous, crystallized substance corresponding to this composition has been already alluded to (Pukall, *Silicat-zeits.*, 2, 1914). It behaves much like melt 1, but is not completely dissolved by water. The insoluble portion consists of clear, microscopically small, well-formed, doubly refracting crystals of longish, almost rectangular, form. Some combinations seem to indicate that they belong to the monoclinic system.

The crystals are always less than a third of the substance used, but increase in amount with decrease of water. Although the crystalline powder by longer contact makes the water feebly alkaline, yet it obstinately resists complete solution even in boiling water, and even after months kept in water it appears still completely unchanged externally, the composition corresponding to $4{\cdot}02SiO_2.K_2O.1{\cdot}22H_2O$, or about $K_2H_2Si_4O_{10}$.

According to this result the same substance is obviously concerned as that which Morey synthesized and called potassium hydrogen disilicate, while he considered its form as belonging to the rhombic system. The behaviour of the body towards water agrees with Morey's account.

A solution of 8 g. of melt 2 ($2SiO_2.K_2O$) completely dried up to a clear glass, furnished with the same treatment not less than 5·14 g. of a sugar-like white substance crystallized in fine large longish almost rectangular plates. Analysis corresponded with the formula $4{\cdot}01SiO_2.K_2O.1{\cdot}06H_2O$, or about $K_2H_2Si_4O_{10}$.

Melt 2 in crystallized as in amorphous condition dissolved very easily and completely in cold and hot water. By evaporation of the solution a syrupy glassy liquid remains, as is characteristic for water-glass solutions. With sufficient dehydration this solidifies to a hard, water-containing glass, which shows on the edges a structure resembling ice-flowers, indicating a tendency to crystallization. On heating to 125° in the air bath the glass-like form disappears, giving a white, friable, water-attracting substance, which under the microscope with crossed nicols shows strong double refraction, and so is crystallized, though the crystal form could not be determined. The loss on ignition amounted to 14·37 per cent., which corresponds to the composition $K_2Si_2O_5+1{\cdot}99H_2O$. The hydrate dissolves in water again easily.

Analysis of the crystallized body formed by direct combination of hydrated silicic acid with potassium hydroxide in presence of little water (0·5 c.cm. to 5 g.) gave results corresponding to the formula $4{\cdot}11SiO_2.K_2O.1{\cdot}21H_2O$, or about $K_2H_2Si_4O_{10}$.

Only 28 per cent. of the theoretical amount was obtained.

Melt 3. $3SiO_2.K_2O$. Of this, 10 g. was used with 2·5 c.c. water, and heated 6½ hours at 180°—192°, forming a snow-white, sugar-like cake. After crushing, washing, and drying, 5·66 g. of gorgeous, doubly refracting, microscopic crystals were obtained, which at once proved to be similar to those finally described from the dried solution of melt 2. Analysis indicated the formula $4SiO_2.K_2O.0{\cdot}92H_2O$, or about $K_2H_2Si_4O_{10}$. A trial on a larger scale with 41 g. of the powder and 11·5 c.c. water, heated for 7 hours at 190° C. yielded 22·8 g. of pure beautifully crystallized substance of similar analysis. Theoretically the equation $2(3SiO_2.K_2O)+H_2O=4SiO_2.K_2O.H_2O+2SiO_2.K_2O$ would give 26·34 g. In the lye the actual presence of the by-product $2SiO_2.K_2O$ was ascertained.

3*a*. *Technical Potash-water-glass*: $3{\cdot}7SiO_2.K_2O$. Solid potash-water-glass of the composition mentioned, procured from Gebr. Bænsch in Dölau, was heated for 7 hours at 192° (25 g. of the powdered substance with 5 c.c. water). The result was a greyish-white, crystalline, coherent cake, which after pulverizing, washing and drying gave 20·7 g. of beautifully crystallized, doubly refracting substance of the crystal form previously described, potassium tetrasilicate. Analysis indicated the formula: $3{\cdot}94SiO_2.K_2O.1{\cdot}15H_2O$, or about $K_2H_2Si_4O_{10}$. The body also corresponds in its other behaviour with potassium tetrasilicate.

Melt 4. $4SiO_2.K_2O$. Of this, 10 g. with 5 c.c. water, was heated 6½ hours at 180°—192°. The result was a marble-like, brilliantly white, tolerably hard crystal cake. Under the microscope the body revealed a very briskly developed

double refraction, but deviates in its further appearance from the crystals hitherto described inasmuch as to the well known crystal plates of almost rectangular form were added also a number of entangled needle-clusters. Analysis indicated the formula $5{\cdot}35SiO_2{\cdot}K_2O.1{\cdot}28H_2O$. As microscopic appearance indicated already, it is thus a question of a mixture of several silicated salts, to be described further on.

To ascertain whether the variable behaviour might be traced to some error in the production of the melt a new melt *4a* was prepared from the calculated quantities of quartz sand and potassium carbonate, and melted in a crucible at cone 7 (about 1,270°) in the fire of a small porcelain oven. 45 g. of the powdered, clear, soft glass, free from bubbles, was moistened with 12·5 c.c. water, and treated in the tube under pressure for 7 hours at 190°. The crystalline, strongly doubly-refracting and well washed substance amounted to 40·14 g. Analysis indicated the formula: $4{\cdot}23SiO_2.K_2O.1{\cdot}14H_2O$. Microscopic appearance showed also in this case a mixture of another body, crystallizing in needles or columns, with the potassium tetrasilicate.

Melt 5. $5SiO_2.K_2O$. 100 g. of the coarsely powdered clear glass was heated with 5 c.c. water for 6½ hours at 180—192°. The moderately hard, sugar-like mass was completely crystalline. But the crystal form deviated considerably from that of the tetrasilicate, inasmuch as it approached the column or needle shape and formed small clusters of entangled little crystals. The yield of crystals amounted to 6·01 g. Analysis indicated the formula: $5{\cdot}94SiO_2.K_2O.1{\cdot}33H_2O$, about $K_2H_2.Si_6O_{14}$, a compound not hitherto known to the author. Apart from the crystal form and its chemical composition it does not differ from the potassium tetrasilicate in its behaviour towards water and acids.

On purification of this compound by washing, a circumstance which much favours the process comes into prominence. After powdering, sieving, and stirring up in water for the removal of soluble by-products, a particularly large portion remains in suspension, while the bulk rapidly settles down. The milky product, which passed through every paper filter was collected and freed from alkaline water by a clay filter. After three to four decantations the washing water remained clear and gave only slight alkaline reaction, so that the bulk of the substance can be prepared quite pure in this way, so far as the latter can be attained at all without the possibility of crystallizing. Under the microscope the suspended particles, of which 1·15 g. was collected, seemed to consist, besides fragments of crystals, of very small, feebly doubly refracting, briskly moving little rods with blunt ends. Analysis indicated the formula: $7{\cdot}95SiO_2.K_2O+1{\cdot}82H_2O$.

In spite of the simple proportion numbers of the molecule, it still remains doubtful whether it is a homogeneous substance or merely a mixture of fine crystal fragments of the true compound, potassium hexasilicate, with very finely divided so-called colloidal silicic acid.

A second kind of suspended particle, which was obtained on the occasion of the treatment with superheated steam of another glass, *5a*, of the composition $4{\cdot}6SiO_2.K_2O$, and under the microscope appeared quite similar, gave on analysis figures indicating the formula $6{\cdot}82SiO_2.K_2O+2{\cdot}04H_2O$. From the disagreement of the two analyses it follows that those suspended particles are mixtures of finely divided crystallized substance and (probably) very finely pulverized silicic acid.

The yield of crystallized substance in this latter case amounted to 18·62 g. from 25 g. of glass powder *5a*. Microscope tests, however, lead one to suspect that it is a question of a mixture of two salts differing from one another in crystal form. Analysis indicates the formula $4{\cdot}87SiO_2.K_2O.1{\cdot}20H_2O$.

For the study of the action of superheated steam on the same substance already purified and analysed, a trial of 3·6 g. served. The body remained practically unchanged, although in washing some remained suspended, and the weight had diminished to 3·3 g. Analysis confirmed the assumption completely, indicating the formula $4{\cdot}88SiO_2.K_2O.1{\cdot}09H_2O$.

Melt 6. $6SiO_2.K_2O$. Of the coarsely powdered glass, which had been tolerably clear by repeated heating at about 1,270°, 5 g. mixed with 2·5 c.c. water was heated for 6½ hours at 180—192° C. The smaller portion was converted into an opaque, ivory-like, crystalline mass, while the greater portion seemed glassy and had the appearance of a dried up silica jelly. The crystalline, hard, coherent mass showed under the microscope clusters of entangled needles or fine plates with high double refraction, which look not unlike the potassium hexasilicate. Analysis indicated the formula: $7·71SiO_2.K_2O.1·88H_2O$.

A larger portion of the same coarsely powdered melt was treated for 6½ hours in exactly the same way. It seemed crystallized throughout, but the double refraction did not show the brightness observed at first.

Still another treatment in exactly the same way gave a snow-white, sugar-like form easily crushed, and left behind after washing and after the loss of 3·9 g. of suspended particles, a beautifully crystallized residue of microscopic, extremely fine needles or plates growing in groups, amounting to 16·1 g. Analysis indicated the formula $8·48SiO_2.K_2O.1·16H_2O$. After long and extremely careful washing a new analysis indicated $8·47SiO_2.K_2O.$ $1·19H_2O$.

Another melt 6[1] at higher temperature (cone 9) and for a longer time resulted in a fine clear glass without cracks and without crystallites. 30 g. of coarse powder of this last-named melt was moistened with 9·6 c.c. water and heated for 6½ hours at 185—190° in a closed tube as before. The result was a hard, finely crystalline cake. Under the microscope the finely powdered and well washed substance showed strongly doubly refracting fragments from entangled fine needles or little plates. Analysis indicated the formula: $5·93SiO_2.K_2O.1·04H_2O$, or about $K_2H_2Si_6O_{14}$.

Melt 6*a*. $7SiO_2.K_2O$. The melt in this case formed a clear greenish glass, which only around the crucible wall formed an opaque white incrustation free from crystallites. The melting took place in a small porcelain oven at about 1,300—1,350° (cone 9—11). 2·5 g. of the powdered substance was moistened with 1·25 and 0·8 c.c. water respectively, and heated for 6 hours at 190—200°. In both cases a violet brown glass resulted, which contained 9·42 and 8·72 per cent. of water respectively, and after ignition completely lost their glassy appearance. But when 35 g. of the same substance with 11 c.c. water was treated in precisely the same way it was transformed into a hard thoroughly crystalline rod, which in powdered condition, and freed from some lye, because the double refraction did not seem bright enough, was a second time treated thus. Now it yielded an easily crushable, snow-white, clear, doubly refracting, crystallized substance, but which by inspection under the microscope was proved to consist of a mixture of two different potassium silicates. Besides entangled needles or little prisms were also found large flat plates, which in their appearance recalled the hydrated potassium tetrasilicate. Analysis confirmed this conjecture, indicating the formula: $7·21SiO_2.$ $K_2O.1·14H_2O$. On washing the powdered substance, much remained in suspension, so that only 25·65 g. remained over. The suspended particles, which certainly even yet contained much crystallized substance, consisted mainly of feebly doubly refracting, briskly moving, little rods.

Melt 6*b*. $8SiO_2.K_2O$. The clear glass cake was obtained under the same conditions precisely as 6*a*. The opaque white zone about the crucible wall was only still wider, and distinct deposits of crystal formation were recognized. Under the microscope it proved to consist of a mixture of crystallized with amorphous.

2·5 g. of the powdered substance, with 1·25 and 0·8 c.c. water respectively on being treated like 6*a* gave uncrystallized glassy looking, brownish masses, possibly similar to those which G. W. Morey mentioned. (See reference in connection with melt 2.) By drying in the water bath the glassy quality disappeared, but the substance suffered on ignition a loss of 9·05 or 9·21 per cent.

35 g. of the original glass powder with 11 c.c. water was treated just as before. But only the extremities of the rod-shaped agglomerated substance proved to be crystallized, of which 1·34 g. was obtained pure. The amorphous

hard residue partly disintegrated in water into a white powder, but partly retained its form. A trial was exposed to superheated steam under the same conditions as before, without any crystallization resulting. Analysis of the small crystallized portion (1·34 g.) indicated the formula: $7{\cdot}57SiO_2.K_2O.1{\cdot}31H_2O$.

30 g. of the same original glass powder with 11 c.c. water was heated for 9 hours at 195—210°, in such a manner as not to interefere with access of vapour (the top of the tube being slightly perforated, and then prepared with some lumps of calcined porous clay and 1·5 c.c. water). The result was a hard completely crystallized or crystalline stick of the shape of the tube. The small quantity of the liquid which was found in the tube reacted strongly alkaline, and contained a small quantity of silicic acid in solution.

The powdered substance shows bright double refraction, and, viewed under the microscope consists of stout plates, apparently of the same crystal form as the hydrated potassium tetrasilicate, for which it is likely to be mistaken. The yield of pure crystallized substance amounted to 24·77 g. The particles obtained in suspension by washing, weighing 5·12 g., also showed much crystallized portion. The rest consists of the above-mentioned little rods of probably colloidal silicic acid.

Analysis of the substance indicated the formula: $7{\cdot}86SiO_2.K_2O.1{\cdot}14H_2O$, or about $K_2H_2Si_8O_{18}$.

This substance, like all hitherto described, is not quite capable of resisting water. With rapid washing the alkaline reaction with phenolphthalein almost completely disappears. But if the substance be then some time in contact with pure water, it returns again. Only little goes into solution, and not merely alkali, but also silicic acid. It is not improbable that, even if very slowly, potassium silicate soluble in water, permanently poor in silicic acid, splits off.

Mixtures of $10SiO_2.K_2O$ and $12SiO_2.K_2O$ were melted at about 1,270° (cone 12) and obtained in completely crystalline condition from the oven, and in both cases finely crystallized substances were obtained by treatment in tubes. The author was still engaged in studying these.

From the foregoing one thing stands out clearly, namely, that only those homogeneous bodies with an even number of silica molecules are able to provide those with uneven number, but only mixtures of such. Only with the lower members does that seem to apply also to those with uneven silica numbers, if the one ingredient of the mixture of crystallized silicates originating in treatment with superheated steam is soluble in water, which certainly furthers the advantage of the other.

The following are the homogeneous crystallized potassium silicates brought into prominence in this work: 1. $K_2SiO_3+2H_2O$. 2. $K_2Si_2O_5+2H_2O$. 3. $K_2H_2Si_4O_{10}$. 4. $K_2H_2Si_6O_{14}$, and 5. $K_2H_2Si_8O_{18}$.

In the following table the chief results in the potash series are clearly grouped. (See page 90).

Behaviour towards water. Substance 1 is apparently obtainable in crystallized condition only under the action of superheated steam, but it scarcely differs in its properties from the original glass substance. Both are deliquescent in the air and clearly soluble in a very small quantity of water. In solution not a single crystal is found of substance 3, which arises from 2 under the influence of superheated steam. Were that the case, the assumption that 1 may be merely a derivative of disilicic acid, possibly the normal salt $K_4Si_2O_6+4H_2O$ would find strong support.

The substance 2 does not need superheated steam for its production. The melt from which it is obtained is by prolonged heating near its melting point easily made to crystallize. The cake crumbles with crushing, into fine-grained elongated pieces, which show columnar structure. Both the amorphous and the crystallized substance are easily and completely soluble in water. On evaporating the solution and heating the residue at 125° in the air-bath, the hygroscopic hydrate mentioned under melt 2 is obtained. Its solution is absolutely stable for all dilutions. It is very probable (as will be shown later) that this substance forms the parent for an altogether new series of silicates.

POTASH SERIES SUMMARY.

No. of Melt	Composition of Melt	Condition	Behaviour with water	Formation of Crystallized Hydrates — Pressure and Temperature: Ordinary	Formation of Crystallized Hydrates — Pressure and Temperature: Increased	Homogeneous Bodies in rounded — Open: Formula	Homogeneous Bodies in rounded — Closed: Formula	Remarks
1	$SiO_2.K_2O$	Amorphous	Easily soluble		$K_2SiO_3+1{\cdot}81H_2O$	$K_2SiO_3+2H_2O$[1]		
2	$2SiO_2.K_2O$	Amorphous and crystalline	,, ,,	$K_2Si_2O_5+1{\cdot}99H_2O$	$4{\cdot}02SiO_2.K_2O.1{\cdot}22H_2O$	$4SiO_2.K_2O.H_2O$	$K_2H_2Si_4O_{10}$	The hydrate provides stronger yield
3	$3SiO_2.K_2O$	Amorphous	,, ,,		$4{\cdot}0SiO_2.K_2O.0{\cdot}92H_2O$	$4SiO_2.K_2O.H_2O$	$K_2H_2Si_4O_{10}$	Best method for producing
3a	$3{\cdot}7SiO_2.K_2O$	,,	Difficultly soluble		$3{\cdot}94SiO_2.K_2O.1{\cdot}15H_2O$	$4SiO_2.K_2O.H_2O$	$K_2H_2Si_4O_{10}$	Technical water-glass in solid form
4	$4SiO_2.K_2O$	,,	Easily soluble		$5{\cdot}35SiO_2.K_2O\ 1{\cdot}28H_2O$			
4a	$4SiO_2.K_2O$	,,	Soluble		$4{\cdot}23SiO_2.K_2O.1{\cdot}14H_2O$			
5	$5SiO_2.K_2O$	,,	Difficultly soluble		$5{\cdot}94SiO_2.K_2O.1{\cdot}33H_2O$			
5a	$4{\cdot}6SiO_2.K_2O$	,,	,, ,,		$4{\cdot}87SiO_2.K_2O.1{\cdot}20H_2O$	$6SiO_2.K_2O.H_2O$	$K_2H_2Si_6O_{14}$	
6	$6SiO_2.K_2O$	,,	Partly soluble		$7{\cdot}71SiO_2.K_2O.1{\cdot}88H_2O$			
6	$6SiO_2.K_2O$	,,	,, ,,		$8{\cdot}48SiO_2.K_2O.1{\cdot}16H_2O$			
6	$6SiO_2.K_2O$	,,	Little soluble		$5{\cdot}93SiO_2.K_2O.1{\cdot}04H_2O$	$6SiO_2.K_2O.H_2O$	$K_2H_2Si_6O_{14}$	
6a	$7SiO_2.K_2O$	,,	,, ,,		$7{\cdot}21SiO_2.K_2O.1{\cdot}14H_2O$			
6b	$8SiO_2.K_2O$	,,	,, ,,		$7{\cdot}86SiO_2.K_2O.1{\cdot}14H_2O$	$8SiO_2.K_2O.H_2O$	$K_2H_2Si_8O_{18}$	

[1] From the difficulty of preparing the crystallized product pure, it remains doubtful whether it is really K_2SiO_3 or a hydrate of $K_2Si_2O_5$

In the case of substances 3, 4 and 5, the molecule H_2O taken up in the process of crystallization is not to be conceived as merely water of crystallization, but as an essential component inserted in the construction of the new molecule, the bulk of which escapes first at a red heat, that is, at the commencement of the melting process, with the destruction of the crystalline particles. Substances 3, 4 and 5 are rather to be claimed as true zeolites, whose properties very closely agree with those of the minerals designated by that name, although these substances contain no alumina.

Substance 3 ($K_2H_2Si_4O_{10}$) and three different preparations of substance 4 ($K_2H_2Si_6O_{14}$) were very gradually (in 9·5 hours) heated up to 350°, and kept at that for three hours. The loss was 1·33, 1·28, 0·92, and 0·20 per cent. respectively, which it was concluded could only be regarded as mechanically adhering water.

Cold distilled water in eight days was found to dissolve approximately equal quantities of $K_2H_2Si_4O_{10}$, $K_2H_2Si_6O_{14}$, and two preparations of $K_2H_2Si_8O_{18}$, in the hydrated and anhydrous conditions respectively, and in no case did the dissolved material amount to 0·04 per cent. Analyses of the residues indicated the proportions $SiO_2 : K_2O : H_2O$ as 1·89 : 1·00 : 3·49, 2·11 : 1·00 : 2·90, 1·48 : 1·00 : 2·73, and 2·04 : 1·00 : 2·60 respectively for the four substances. Thus in almost all cases $SiO_2 : K_2O$ is 2 : 1, and the conjecture that no solution takes place, but rather a disunion in favour of the easily soluble silicate, $K_2Si_2O_5+xH_2O$, is confirmed in astonishing manner. What was constructed through the influence (on the melts) of little water under strong pressure, is gradually destroyed by the action of much water under ordinary pressure.

The action of hot distilled water was tested by heating similar trials, omitting the fourth, in covered vessels with distilled water over the water bath for 24 hours. The hot water acted unequally on the substances, the highest proportion dissolved being 0·20 per cent. of hydrated $K_2H_2Si_4O_{10}$. Analyses of the residues of the solutions indicated the proportions of $SiO_2 : K_2O : H_2O$ as 1·06 : 1·00 : 1·77, 1·19 : 1·00 : 2·86, and 1·36 : 1·00 : 3·62 respectively. Thus the richer in alkali the substance, the more the separated substance in solution approximates to the proportion 1 : 1 for $SiO_2 : K_2O$. It follows that the first separated substance, $K_2Si_2O_5$ or $K_2H_2Si_2O_6$, by taking up water suffers a new separation into silicic acid and potassium metasilicate, whereupon also increasing turbidity of the liquid by colloidal silicic acid during the action seems to be indicated.

The external form of the substance is scarcely changed by the leaching out process.

Behaviour towards acids. It was assumed that acids would act similarly to water, but with the difference that all the silicic acid would stay in the residue, and only potash go into solution. Only one test was made—with potassium silicate—and in this case the assumption was fully confirmed. The ignited residue was found to be silica with less than 1 per cent. of impurity.

Soda Series: *Melt* 7. $SiO_2.Na_2O$. This melt, crystallizing in splendid silky needles, has already received public mention, and its hydrates a detailed description.

4 g. of the substance in crystallized needles and 0·6 c.c. water were heated together (in closed tube) at 180—195°. The substance seemed externally unchanged. Only a small portion of the (original) substance consisted of more difficultly soluble stout crystal needles, which could be recognised as the disilicate $Na_2Si_2O_5$. After solution of even this substance, a trace of mud remained consisting of very fine needles, which consisted of pure silica.

Melt 8. $2SiO_2.Na_2O$. This forms a clear glass, which only seldom shows tendency to crystallize during the cooling, though it passes easily and completely into the crystallized condition if the coarse powder or the glass block be heated at its melting point for 1—2 hours. The substance then forms incrustations, which consist of densely crowded, parallel, columns or little rods. The amorphous melts dissolve completely and rather easily in water. The crystallized substance—which is rather difficultly soluble—always leaves a small quantity of substance crystallized in very fine needles and showing

quite feeble double refraction; it consists of pure silica. It is also in this case a question of a borrowed or acquired form, as in the cases of that mentioned above and also observed with Na_2SiO_3. 5 g. left 0·14 g. or 2·8 per cent.

Four experiments were made with the closed tube, the water used for 1 g. being 0·8 to 0·58 c.c., without affecting the final result. The product in each case was a sintered mass soft to the touch, greyish brown, resembling soapstone, and adhered so firmly to the glass that the latter had to be removed from the core by grinding off. The final result is also unaffected by the use of crystallized or amorphous material. The temperature fluctuated between 180—200°, but in one special case it was observed that even at 150° a satisfactory effect could be produced. With the use of very little water (0·08 c.c. or 1 drop to 1 g.) the reaction-substance coalesced into a stick, was tolerably hard and the outlines of the diminutive crystals combined in it only ascertained with difficulty. But they stand out very finely with the use of more water (up to 0·5 c.c. to 1 g. of substance), a part then passing into a viscid mass. In this case very beautifully defined hexagonal tables with high double refraction can be distinguished under the microscope. The substance is so easily soluble in water that it could not be washed. It was therefore allowed to stand some time in powdered condition with strong alcohol, dried and analysed. The results indicated the formula: $2SiO_2.Na_2O+0{\cdot}48H_2O$, or about $Na_2Si_2O_5+0{\cdot}5H_2O$.

The results of analysis show that from treatment of sodium disilicate with superheated steam arises only a hydrate poor in water of crystallization, which on account of its crystalline form being quite different from that of the mother substance, and its easy solubility, must be claimed as an independent substance. There is no sign of the passage, even of only a part of the substance, into a more highly silicated form, as happened with the corresponding potassium salt.

Melt 9. $3SiO_2.Na_2O$. The difference in behaviour of sodium compounds from the corresponding potassium compounds continues in the melts with increasing silica content in the sense that all without exception are changed by superheated steam into crystallized, firmly coherent, strongly doubly refracting substances, which resemble one another completely, and very often under the microscope distinct hexagonal plates can be recognised, which in contact with water decomposes at once into a solution of sodium disilicate and silicic acid. The latter appears in most cases in the form of very small rods which for the most part remain suspended in water a very long time, under the microscope execute very lively movements, show only feeble double refraction, and pass through every filter paper. It is thus a question probably of a colloidal form of silicic acid. In other cases the silicic acid appears in a more compact form, which appears deceptively like fine native quartz sand, but contains water and shows a somewhat smaller amount of double refraction. In this case no colloid formation takes place, or it is only trifling. The process seems to depend on more or less water pressure, but is not yet fully investigated. It is intelligible that with increasing silica content of the melts the separations of silicic acid become greater, the portion going into solution smaller, and *vice versa*.

The *technical solid soda water-glass* appears to be of great interest with regard to its behaviour towards superheated steam; 9*a* (supplied by Gebr. Bænsch in Dölau near Halle). Its composition according to an analysis corresponds to the formula $3{\cdot}4SiO_2.Na_2O$. 25 g. with 3 c.c. water was treated in the usual way for 7 hours at 190—192°. The product was a greatly contracted, stone-hard rod with marble-like fracture, the powder of which under the microscope showed only very slight double refraction. Small pieces heated on platinum foil swell more strongly than borax, and form a light, frothy mass, which floats on water, but since part of the substance dissolves soon shrivels and sinks to the bottom. Morey reports quite similar phenomena, which occur more or less strongly with all similarly treated soda melts.

If an unchanged piece (of the rod) be placed in water, it decomposes rather quickly into a granular substance resembling quartz sand, while another

considerable portion goes into solution. 18·76 g. left 3·04 g. of a white uniform-grained mass resembling quartz sand, and which, viewed under the microscope, looked quite like native quartz sand grains, and also as regards double refraction was not far behind it. It differed only by its water content, which on heating escaped with distinct scattering of the grains. Analysis indicated for the dissolved portion (after evaporation to dryness) the formula: $2{\cdot}10SiO_2.Na_2O$, about $Na_2Si_2O_5$. The soluble hydrate gave analytical results indicating the formula $Na_2Si_2O_5+2H_2O$. (This last was after evaporating another portion of the same solution to dryness in an air bath at 125—130°.) The residue (3·04 g.), resembling quartz sand, gave results indicating the formula: $2{\cdot}95SiO_2.H_2O$, or $H_2Si_3O_7$.

Melt 10. $4SiO_2.Na_2O$. This melt, like the foregoing, forms a clear glass without bubbles, which only about the crucible wall was surrounded by a devitrified, friable zone about 3 mm. thick, which under the microscope partially showed crystalline tendencies. A 6 hours' treatment of 1 g. of the melt with 0·3 c.c. water provided a finely crystallized substance, which in alcohol under the microscope with crossed nicols showed lively double refraction, but in contact with water at once decomposes in the way mentioned above. The substance was washed with alcohol, and since it gave the impression of a homogeneous substance it was subjected to analysis, which indicated the formula: $4SiO_2.Na_2O+2{\cdot}3H_2O$. The results of investigation of the product of decomposition by water indicated for the soluble portion a composition represented by the formula: $1{\cdot}82SiO_2.Na_2O.3{\cdot}35H_2O$, for the insoluble portion: $2{\cdot}21SiO_2.H_2O$, and for the original substance: $3{\cdot}87SiO_2.Na_2O.4{\cdot}10H_2O$. The higher water content of the original substance (4·1 mol.) is explained by an experiment from another preparation which had not previously been treated with strong alcohol, but was used in air dried condition. It appears that in the former 2 mol. of the loosely combined water of hydration was withdrawn by the alcohol.

It thus obviously follows that sodium disilicate was again separated, while disilicic acid remained.

Melt 11. $5SiO_2.Na_2O$. The mixture of sodium bicarbonate and quartz sand was completely melted at cone 9 (1,310°). The cooled glass cake appeared quite opaque and was surrounded from the edge outwards to a width of 1—1·5 cm. with a crystalline layer. Treatment of the glass powder with a little water as before led to quite a similar result as in the previous cases; to a greyish brown, crystalline substance, which with water decomposed in part to a white powder, in part went into solution. A closer investigation of the decomposition substance has not taken place.

Melt 12. $6SiO_2.Na_2O$. This is much more interesting than melt 11, because under the same conditions as the preceding received, it came from the oven completely crystallized. It no longer concerns that obtained above at 1,270°, but one of the same composition completely melted in the crucible at 1,310—1,350°. After powdering, 15 grms. was again melted at about 1,400°. The result remained the same, but in a few small bubble spaces were noticed with the naked eye crystals in the form of hexagonal laminæ. This fact was confirmed by microscopic examination of the powder, when individual crystals appear with perfect boundaries.

2·5 grms. with 0·8 c.c. water heated 6½ hours at 190—200° yielded a crystalline melt resembling soapstone, which decomposed in water, part going into solution, while part remained as a powder resembling quartz sand, like that already observed in soda water-glass. But the grains in this case were coarser and had a stronger double refraction. The residue resembling quartz sand was proved to consist of almost pure silica.

The reactions again in this case in the decomposition by cold water of the products of reaction arising under the influence of superheated steam proved very interesting. The substance came in powdered air-dried form for use. Analysis indicated for the soluble component the formula: $1{\cdot}29SiO_2.Na_2O.4{\cdot}32H_2O$, and for the insoluble component the formula: $2{\cdot}88SiO_2.H_2O$, whilst for the original substance was indicated the formula $5{\cdot}51SiO_2.Na_2O.5{\cdot}65H_2O$.

From the result the course of the separation is not to be recognised as was that in the case of melt 10. While $H_2Si_3O_7$ remained, a mixture of metasilicate and disilicate went into solution.

In *melt* 12*a*, $7SiO_2.Na_2O$, the results were more or less repeated.

Melt 12*b*. $8SiO_2.Na_2O$. The mixture was melted at about 1,400°, and though brought into fusion, yet the boundaries of previous cavities had not disappeared. The sugar-like white cake, after again melting, was in both cases thoroughly crystallized, the powder showed a high double refraction, and the crystals seem to consist of fine needles arranged more or less parallel.

3 grms. of the substance with a little water was treated in the usual way for 6½ hours at 180—195°. The result differed from that previously described only in so far as in this case the presence of the hydrate crystallizing in hexagonal plates was clearly recognizable. With the admission of much cold water the usual decomposition at once took place, and in order to obtain a clear picture of the mechanism of this process the products were analysed. The residue, which was partly in colloidal condition, consisted, as always, of the oft-mentioned fine, silicic acid rods. Analysis indicated for the soluble portion the formula: $2{\cdot}31SiO_2.Na_2O.4{\cdot}54H_2O$, for the insoluble portion $4{\cdot}78SiO_2.H_2O$, and for the original substance $8{\cdot}18SiO_2.Na_2O.5{\cdot}67H_2O$. It thus appears that essentially sodium disilicate is separated.

6 grms. of the substance with 1·6 c.c. water was heated as before for 7 hours at 242°, the tube finally bursting. The collected fragments of the substance behaved towards water quite as in the other cases, but the white residue had almost entirely lost its colloid nature. Under the microscope appeared now distinct little prisms without individual motion and with considerably strengthened double refraction. In the red it showed generally bright colours. But the water content still amounted to 3·25 per cent. The substance by ignition suffered no change externally. This experiment was made with a view to determining if possible whether the little rods might be considered as embryos of rock crystal, and whether by greatly increased temperature and pressure it might be possible to produce that mineral.

For want of suitable sources of temperatures above 1,400° the trials in the soda series had to be broken off.

In the soda series by the action of superheated steam only a single compound has been ascertained with certainty, the hydrate of disilicic acid ($Na_2Si_2O_5+0{\cdot}5H_2O$) crystallizing in hexagonal plates. Perhaps the formula should be doubled, giving $Na_4H_2Si_4O_{11}$. All the rest seem, so far as they under the microscope in neutral liquid evoke the impression of uniformity, to consist only of mixtures of that compound with silicic acid separated and appearing in the form of the oft-mentioned sand or of little rods. Otherwise it was not understood why the silicic acid, got by splitting off or deposition, should not retain, as in the potash series, the crystal form of the compound from which it was separated through decomposition by water. After all, the soda series in relation to obtaining substances parallel to those of potassium has almost entirely failed. It is an extraordinary circumstance that in presence of alumina no disunion results.

It will remain for future investigation to ascertain which of the remaining silicate-forming alkalies, alkaline earths, earths, heavy metals, are connected with one or other series, and how far superheated steam is in a position to exercise a transforming influence also on non-silicates.

Theoretical.

Counting from the metasilicate upwards, in the potassium series of melts, the member $K_2Si_2O_5$ and those from $K_2Si_{10}O_{21}$ upwards can be obtained crystalline without difficulty. In the transformation series (produced by the action of superheated steam)—apart from K_2SiO_3, concerning the nature of which doubt still exists—only the members with silicon atoms present in pairs after taking up one molecule of water into their molecular structure pass with ease into the finely crystallized condition, and in their properties are analogous rather to the natural silicates, the zeolites.

With sodium, in the melt series, the compounds Na_2SiO_3, $Na_2Si_2O_5$, and those from $Na_2Si_6O_{13}$ upwards crystallize. In the transformation series it remains doubtful in all but one case whether the crystalline products are real homogeneous substances corresponding to the potassium compounds, only unstable towards water, or whether the division into silicic acid and (essentially) sodium disilicate already during the preparation came to a complete breach. The latter assumption is much more probable.

The silicates of the melt series, the true water-glasses, are more or less easily soluble in water with partial decomposition. An essential difference between those of potassium and sodium can scarcely be established. The silica content of the soluble compounds point to about four molecules to one molecule of alkali. The solutions form in the more or less concentrated condition glutinous, somewhat thick, liquids, which for the most part contain all the compounds mentioned and thus give the technical water-glass solutions. By decomposition with acids, voluminous, gelatinous silicic acid separates.

The compounds of the transformation series are with potassium, excepting the first member, $K_2Si_2O_5$, although containing water, like the natural zeolites insoluble in water, but undergo with cold water a slow, with hot water and with acid an accelerated decomposition into a poorer silicic acid with two silicon atoms on the one hand and potassium disilicate on the other hand. The separated silicic acids retain with potassium the form of the crystallized salt from which they originated; with sodium they appear sometimes in the form of crystalline sand, sometimes in the form of more or less colloidal rods, but never in the form of jelly.

By the action of superheated steam, silicate-glasses, whether themselves amorphous or crystallized, undergo a thorough transformation. The reaction mass always appears in a compact, sometimes stone-hard form, quite as if it had undergone a remelting. If crystallization does not take place, the mass ordinarily shows a glassy condition.

It is suggested that the compounds in the melts are simple or complex derivatives of metasilicic acid, H_2SiO_3 or $(OH)_2SiO$. Thus potassium tetrasilicate is represented as $OK.Si.\overset{\cdot\cdot}{O}.Si.\overset{\cdot\cdot}{O}.Si.\overset{\cdot\cdot}{O}.Si.\overset{\cdot\cdot}{O}.OK = K_2Si_4O_9$, and K_2SiO_3. $K_2Si_2O_5.K_2Si_3O_7$, etc., can be represented in similar manner.

The substances in the transformation series are regarded as derived from orthosilicic acid H_4SiO_4 or $Si(OH)_4$. Disilicic acid is derived from two molecules of orthosilicic acid by elimination of two molecules of water, thus

$$\begin{matrix} OH-\\ OH-\end{matrix}Si\begin{matrix} -OH\\ -OH\end{matrix} + \begin{matrix} OH-\\ OH-\end{matrix}Si\begin{matrix} -OH\\ -OH\end{matrix} = \begin{matrix} OH-\\ OH-\end{matrix}Si\begin{matrix} -O-\\ -O-\end{matrix}Si\begin{matrix} -OH\\ -OH\end{matrix} = H_4Si_2O_6.$$

Potassium tetrasilicate is $\begin{matrix} OH-\\ OH-\end{matrix}Si\begin{matrix} -O-\\ -O-\end{matrix}Si\begin{matrix} -O-\\ -O-\end{matrix}Si\begin{matrix} -O\\ -O\end{matrix}Si\begin{matrix} -O-K\\ -O-K\end{matrix} = K_2H_2Si_4O_{10}.$

Concluding Remarks.

Zeolites as well as many other double silicates can be conceived as reacting just as well as compounds of alkaline or alkaline earth silicates with aluminates and ferrites, both of which latter groups certainly play a very important part, in nature just as in technics. It is not easy to understand why these well characterised compounds have hitherto been considered worthy of scarcely any notice in scientific chemistry.

Sand of any origin and grain, gravel, clay, calcined or uncalcined, granite fragments, etc., mixed with little more than 10 per cent. of the highly silicified alkali-silicate melt and pressed together, combine in superheated steam to considerable hardness, which does not differ essentially from that of natural sandstone, clay-slate, etc.

Of the artificial stone samples thus obtained only those cemented with potassium silicate are durable in water, and when fixed for a time some potassium disilicate is given up, thus the alkali is gradually lost, but nothing is lost in hardness. Those obtained with sodium silicate melts decompose, on the contrary, in spite of originally greater hardness, completely in water within a short time.

MICROSTRUCTURE OF TWO FIRED CLAYS.—H. Ries and Y. Oinouye (*Bull. Amer. Inst. Min. Engineers*, p. 1,421, 1917). Two clays were investigated, a brown clay and a greyish-white residual clay, both from Virginia. The texture increased in density with the time of firing up to a certain point, and there was a gradual increase in the amount of isotropic material present. Corrosive action in the quartz also increases with the time of firing, and pore spaces begin to be formed at 1,150° C. The hydromica is more fusible than kaolinite, but fusion proceeds in a similar way in both.

MIXING BASIC SLAG WITH NATIVE MAGNESITES.—(*Iron Age*, 99, 535, 1917). The raw magnesite is partially calcined for 4 or 5 hours in an ordinary heating furnace, cupola, rotary kiln, or continuous furnace. The crushed material is mixed with 10 or 15 per cent. of good basic slag. The product has proved equal to any material ever used for back walls of rolling or tilting furnaces. The bottom can be set in half the time required when Austrian magnesite is used. After testing for 8 months on a hearth which was lined right up to the slag line with clay bricks (no magnesite bricks being present), the results were quite equal to those obtained with Austrian magnesite. It is said that exceptionally good results are obtained by using it for closing up tap holes. See also TRANS., 17, *Abs.*, 20 and 24, 1917.—T. Twynam's Eng. Pat. No. 1,463, and C. J. Barr's U.S. Pat. No. 1,206,771.

REINFORCED DOLOMITE AND MAGNESITE.—H. Godfroid (*Iron Age*, 99, 830, 1917). A mixture of ground dolomite or magnesite with tar, to which steel turnings have been added, when rammed into shape can be moulded like reinforced concrete, and repairs can easily be effected.

BAUXITE.—(*J. Industrial and Eng. Chem.*, 9, 620, 1917).—Report by Secretary of the British Chamber of Commerce for the French Riviera, describing rich deposits of bauxite in the districts behind the Riviera.

ORIGIN OF LATERITE.—J. M. Campbell (*Mining Mag.*, 17, 67, 120, etc., 1917). A discussion of the origin, structure, and forms of laterite.

The process by which certain hydroxides (chiefly ferric, aluminium and titanium hydroxides) are deposited in the pores of the superficial portions of a rock possessing an open texture is called laterisation, and laterite is the product resulting from such action. A rock, formed near the surface, which does not contain aluminium hydroxide uncombined (with acids or bases) cannot be considered lateritic. The deposition of iron in laterite takes place primarily as amorphous, highly hydrated ferric hydroxide, formed by atmospheric oxidation of ferrous compounds (chiefly the carbonate) in watery solution. By the prolonged simultaneous action of heat and water this hydroxide is often converted into anhydrous ferric oxide more or less completely. The deposition of alumina in laterite takes place primarily as the amorphous hydroxide ($Al_2O_3.3H_2O$), and this may be mixed (or perhaps combined) with ferric hydroxide, in which case partial or complete segregation usually takes place into gibbsite ($Al_2O_3.3H_2O$) and ferric oxide. The aluminium hydroxide in laterite is derived from hydrated silicate of alumina, which alkaline water is believed to break up with the production of alkaline aluminate and silicate; this action is reversible.

Secondary changes in laterite usually tend towards complete hydration of alumina and complete dehydration of ferric hydroxide; there is also usually a tendency towards removal of iron and consequent production of bauxite. Under favourable conditions nearly pure amorphous aluminium hydroxide (the tri-hydrate) becomes dehydrated, forming an amorphous di-hydrate. In old pisolitic laterite an amorphous aluminium mono-hydrate has been found. Ancient laterites which have passed below water level have their iron leached away, and it is in this manner that most commercial bauxites have originated.

MELTING POINTS OF VARIOUS FIREBRICKS.—W. M. Barr (*Industrial Engineering and Coal Trades Review*, 95, 198, 1917). The melting points

of 45 samples were determined in an electric vacuum furnace, using an optical pyrometer, the results (in degrees C.) being as follows:—

Kaolin ...	1740	Pure alumina	2010	Pure silica ...	1600
Bauxite ...	1820	Bauxite clay...	1795	Chromite ...	2180
Magnesia ...	2165				

FURTHER CONTRIBUTIONS TO THE KNOWLEDGE OF CLAYS.—G. Keppeler (*Berichte der Technisch-wissenschaftlichen Abteilung des Verbandes keramischer Gewerke in Deutschland*, 1913, p. 18). Plasticity is regarded as depending on smallness of particles and on softness of particles. It is clear that with the pulverizing of a substance into smaller and smaller particles the total surface increases. It is well known that water separates on surfaces which are in contact with moist air. It is assumed that this film is of molecular thickness, and consequently it can be utilized in order to obtain information as to the size of the surface. For the determination of the hygroscopicity (power of attracting water) it is recommended to refer to a quite definite humidity of the air. The substances may not be brought over water itself, since in this case the water that can be dropped liquid becomes separated and leads to a thorough soaking of the mass. With the exception of very humous clays the employment of 10 per cent. sulphuric acid has proved useful. The weighed substance (previously dried at 110°) is brought under a bell over 10 per cent. sulphuric acid and exhausted and left there until weight remains constant. The difference of weight in the dry and moist condition corresponds to hygroscopicity. In this way it was found that the percentage of hygroscopic water was 3·02 in Hirschau, 5·88 is Zettlitz kaolin, 7·51 in Lautersheim, 8·00 in Wildstein, 9·03 in Löthain, 9·52 in fine Löthain, and 11·56 in Ebernhahn clay, whilst in "fine quartz" it was 0·70, and in "coarse quartz" 0·40. The Pouillet effect (in cal. per 100 g. clay—see next par.) for the same kaolins and clays respectively amounted to 79·6, 99·1, 174·7, 183·0, 191·9, 276·4 and 305·9; for "fine quartz" it was 14·7, and for Zettlitz kaolin calcined at 1,400° it was 28·0. By arranging the clays according to the amount of attraction for water a sequence is obtained corresponding to the plasticity. Clays which according to experience are very plastic and for which our plasticity measurements have also yielded the highest numbers stand at the head, those resembling kaolins in the middle, kaolins themselves at the end.

A phenomenon resembling hygroscopicity is the Pouillet effect (heat evolved by powders during absorption of hygroscopic moisture). One must imagine that the film of water, which in damping covers the clays, stands under very strong attraction, and is thus compressed. With this compression, of course, heat appears, and this heat again depends on the extent of the damping film. There is thus in the determination of the Pouillet effect a further measure for the size of the surface of a powder, of course with the defect that we do not know what part to assign to the clay itself and what to its impurities. The determinations were carried out with the Bunsen ice-calorimeter, and the numbers are given above.

The determination of the Pouillet effect is likely in general to be too troublesome; the hygroscopicity, as the results of experiments show, gives the same points. It is so simple to carry out that the author proposes its introduction as a means for further characterizing clays, believing it to give a number which is very valuable for estimating clays. Only it must always be determined over 10 per cent. sulphuric acid.

The "coarse quartz" referred to in the foregoing is very finely ground quartz which yields on elutriation 80 per cent. of particles of the fineness of clay substance. "Fine quartz" is the elutriated product corresponding to clay substance. Comparing the hygroscopicity and the Pouillet effects of different clays, it is shown that the difference in the surfaces between the clays and the "fine quartz" is by no means so great. The range from quartz to Hirschau kaolin is not much greater than the interval between Ebernhahn clay and Hirschau kaolin. It must therefore be concluded that the view which was first expressed by Olschewsky, and which the author also was inclined to make his own, that the clay substance in consequence of its origin from felspar is

porous, as it were an ultramicroscopic sponge, cannot meet the case, because in this case the difference between the dense quartz and the assumed porous clay must be very much greater.

Experiments were made to ascertain whether by elutriation a cause could be obtained for the differences in the size of particles of the clay substance. That which Seger obtains as clay substance with his smallest velocity in elutriation takes the largest and the finest particles of clay substance without distinction. To separate Seger's clay substance into fractions of different-sized particles with the normal elutriating apparatus would be too tedious on account of the small velocity of transit. Retaining the form of Schöne-elutriator hitherto used (with Berdel's arrangement of the pressure tube and the fine regulation cock of Simonis), the cylinder was changed to one of 12 times the cross-section. With the very small velocities a warming of the water took place, and with it a separation of air and carbon dioxide. Gas bubbles disturb the elutriation; in order to remove them easily a three-way cock was arranged between the two cylinders. With this apparatus elutriations of 0·02 mm. per second could be carried out. The following results were obtained:

Origin of the Clay	Percentage of Clay substance	Percentage of Clay substance elutriated at			
	0·2 mm per second	0·02 mm. per second	0·07 mm. per second	0·15 mm. per second	0·2 mm. per second
Löthain ..	85	75 5	13·4	7·9	3·2
Lautersheim	75·7	1·7	87·3	7·5	3 5
Wildstein ..	94·0	4 2	82 4	10 9	2·5
Zettlitz ..	94·1	8·2	70·4	8 7	2·7

Here also it is distinctly shown that the fat Löthain clay contains a very much larger percentage of extremely fine material than the kaolin-like clays and the kaolins. In this connection allusion may be made to the fact that the far-reaching fractionation of the material other than clay substance into poor clay, dust sand, fine sand and coarse sand does not thus seen essential. The author believes it would suffice if the residue on the 900-mesh sieve and the 5,000-mesh sieve were determined, and, besides, the content in clay substance ascertained by rational analysis. Continuation of the trials has further shown that in the fractionation of the clay substance, it is best to introduce between the velocities of 0·02 mm. and 0·07 mm. a velocity of 0·05 m. In this way the improved elutriation method seems a means not for determination of the quantity of clay substance, but for closer characterization of it. But it remains questionable whether it exceed in value the simpler determination of water attraction. (See also criticisms of the elutriation process by Parmelee and Moore, *Trans. Amer. Cer. Soc.*, 11, 467, 1909; *Sprech.*, 23, 340, 1910).

The author has previously alluded to the fact that clays at definite temperatures show an increased consumption of heat, and on the other hand at other temperatures themselves develop heat. This has already been worked at from different sides bv Le Chatelier, Rieke, Mellor and Holdcroft, and Sokoloff. Le Chatelier's experiments are fundamental, but very little known. He had the rise of temperature in his trial oven taken photographically, using a thermo-element combined with a mirror galvanometer. In this way Le Chatelier obtained pictures for different clay minerals in his uniformly heated oven, viz.: halloysite, allophane, kaolinite, pyrophyllite, montmorillonite. These pictures are reproduced, and curves are also given showing the same results.

In this work of Le Chatelier there is a certain lack of concordance inasmuch as he assigns the curves which the author finds for all clays and kaolins, besides to clay itself, to halloysite, which according to the author's conception is an allophanoid. On the other hand he finds a different curve for kaolin. A large series of kaolins of German origin has been thoroughly

tested, but a curve has always been obtained like that allotted by Le Chatelier to halloysite, that is to say, with a retardation between 450° and 650°, and with a sudden development of heat between 950° and 1,000°. (Curves are given for an English china clay, five German and one Japanese kaolins). Only with the Japanese kaolin from Roseki was there an irregular heat curve, which has some resemblance with the curve given by Le Chatelier for kaolinite. This discrepancy in Le Chatelier's work is still to be explained.

As regards the explanation of the two heat reactions, there is harmony respecting the consumption of heat between 500° and 600°. All the investigators named are agreed that the consumption of heat is to be traced to removal of water from the molecule of the clay substance. Also tolerable certainty exists on the point that removal of water is associated with a decomposition of the kaolin molecule into free alumina and free silica. Just this decomposition is also drawn upon for the explanation of the development of heat at higher temperature. Alumina itself shows with suitable preparation such a development of heat above 750°. This is explained by the very porous fine alumina at 750° rather suddenly striving to diminish its surface, it accomplishes the result and thereby becomes dense. This diminution of surface takes place with a strong development of heat. Other substances also show this behaviour, particularly precipitated chromic oxide. There the reaction commences at 500°, only a little below the limit of visibility of radiation. By the development of heat this limit is passed, and the chromic oxide glows. Recurring to clay, it is not yet certain whether this sintering of alumina is the sole reason for development of heat in the clay. Comparison of the work of different investigators yields a series of discrepancies, especially with reference to temperatures. Moreover precipitations of alumina with silica show the heat reaction in greater harmony with the clay than pure alumina does.

Artificial precipitation of silica and alumina in the general course of the curve give throughout the picture of allophane, which seems to be a further confirmation of the conception of the allophanoids advocated by Stremme.

[The differences here alluded to have been shown by Dr. Mellor to be due to differences in the rate of heating. See paper entitled "Do Fireclays contain Halloysite or Clayite?" TRANS., 16, 73, 1917, where further references will be found.]

RATIONAL ANALYSIS.—H. Stremme (*Berichte der Technisch-wissenschaftichen Abteilung des Verbandes keramischer Gewerke in Deutschland*, 2, 15, 1914). A discussion as to the validity of rational analysis for technical purposes. It is pointed out that the different methods proposed from time to time give with the same material different results, the discrepancy in the case of insoluble residue amounting to more than 6 per cent. when hydrochloric acid was used, and presumably there would be similar variations if sulphuric acid were employed. Thus it seems necessary to decide on definite concentration, definite proportionate quantities, definite temperature, and definite duration.

By sulphuric acid are dissolved from clays the quantities present of the two groups of clay-minerals so essentially different in their chemical behaviour, those soluble in hydrochloric acid—for the most part colloidal allophanoids (which are mostly plastic, rich in water and have absorptive power)—and the little or less attacked felspar residues (which are often non-plastic, not colloid, poorer in water and of very small adsorptive power). As to whether in practice it is necessary to separate the two clay substances the author expresses no opinion. If it be necessary then van Bemmelen's plan of extracting first with hydrochloric acid and then with sulphuric acid must be adopted. Extraction only with hydrochloric acid did not bring into solution felspar residues (kaolin, etc.) in raw clays; with burned clays essentially larger quantities of these dissolve.

But the action of sulphuric acid goes even further, it attacks undecomposed silicates like alkali felspars, mica, pyroxene, amphibole, garnets, etc., and completely dissolves others like anorthite, leucite, nepheline, etc. Most important is the behaviour of sulphuric acid towards alkali felspars, which in

view of their great distribution in clay rocks and their importance for the clay industry would always be considered most.

Alkali felspar is regarded as a prominent little-soluble mineral. But with minerals the effect of treatment is dependent on size of grain, quantity and concentration of acid, temperature and duration of action. This limits the validity of rational analysis.

A second limitation is perhaps applicable for such clays as contain humus substances in noteworthy quantity; thus for many lignite clays, but also for many kaolins. In Bollenbach's modification of rational analysis the disturbance of the analytical process by the presence of humus is taken into account. Bollenbach recommends the addition of nitric acid for the destruction of the humus. If this does not happen, then silica is found mixed with all the other components

The author concludes from these and other considerations that the rational determination of clay substance cannot be regarded as an exact analysis. According to experience with soils, it is advisable to choose that concentration of sulphuric acid which has a constant boiling point. This boiling temperature is the temperature of decomposition.

Quantity of sulphuric acid and duration of the test must be arranged according to solubility of the clay substances and according to the susceptibility to attack, particularly of alkali felspars.

Before carrying out the analysis any pulverizing of the clay exceeding a superficial crushing should be avoided.

ABSORPTIVE CAPACITY OF PLASTER MOULDS.—O. Rose (*Ker. Rund.*, 23, 97, 1915). With fancy porcelain, for which a very weak and fine body is aimed at, the moulds must have a very great absorptive power. Through the strong porosity of the mould the rapid absorption of water prevents all formation of bubbles, and the very thin piece is much more easily loosened from the mould. Moreover a porous mold is not so easily damaged by rotting, for the air has better access.

Unequally strong absorptive power of the mould arises when the plaster is thrown from the shovel suddenly into the mixing water. It then often does not soften through uniformly and forms lumps. To prevent this formation of lumps, in putting into the water the plaster should be allowed to slip from the shovel through the fingers in order to divide it as finely as possible. Then by constant movement deposition of the plaster powder must be prevented. This movement must even be continued after the plaster has been poured over the model, for if this has deepened places the plaster readily deposits a thicker layer here, and these places appearing in the mould as elevations do not absorb so well as the level surfaces. Cast porcelain objects in the raised places of the mould are often observed weaker and adhere to the mould. The plaster mould in such cases withdraws the water from the porcelain slip more slowly in the raised places than in the others, and so an uneven thickness is produced, which causes a greater loss in manufacture.

Strengthening of absorptive power of the plaster mould is only effected by the manner of mixing, for the less plaster is stirred up in water the greater is the absorptive power of the cast mould. But as absorptive power of the mould increases so also does the fragility, and its durability decreases, so that great care is necessary in the treatment of such moulds.

For this reason plaster moulds of great absorptive power are not to be recommended in the manufacture of vessels, but more attention should be given to the preparation and working of the mixture of plaster and water. The wavy surface often found in large vessels made by the soda casting process is to be traced more or less to irregular mixing of plaster and water.

BY-PRODUCTS OR WASTE IN THE CLAY INDUSTRY.—(*Ker. Rund.*, 23, 253, 266, 280, 1915). M. Roesler refers to used *plaster moulds*, which mostly go to the refuse heaps of the factories. They could be dealt with in many ways. Their preparation for moulds again, of course, produces no good result, but old moulds could be pulverized, mixed with clinker and ashes, and by a

comparatively small addition of hydraulic lime form building stones which can quite well be substituted for Rhenish pumice stone in inner walls and fillings not exposed to moisture. The fine portions of the crushed moulds if burned in a cupola can be used as part substitute for the lime mortar to the stone. Used plaster moulds can be employed as a fertilizer, as the author himself has found to great advantage.

Clinker is another waste material. This can be used for improving the roads. The sandy material from the oven ashes can be used to make good mortar, using two measures to one of fat lime and one of building sand.

RATIONAL ANALYSIS AND COMPOSITION OF CLAYS.—(*Ker. Rund.*, 23, 195, 208, 228, 245, 265, 279, 1915). Based on Georges Vogt's work published in 1897.

DEPENDENCE OF EXPANSION COEFFICIENT OF HARD PORCELAIN ON THE BURNING TEMPERATURE.—C. Tostmann (*Ker. Rund.*, 23, 219, 1915). Refers to a paper by Rieke and Steger (*Sprech.*, 48, 297, 1915), and calls attention to similar work by Coupeau and by Chantepie published in 1898 and 1901 respectively, and observations thereon by Vogt. R. Rieke replies, and there is a rejoinder by Tostmann.

CRAZING AND EXPANSION COEFFICIENT.—C. Tostmann (*Ker. Rund.*, 23, 228, 1915). Tiles were set in a muffle so that their unglazed backs leaned against the heated walls of the muffle. The body of the tile was thus strongly heated before the temperature of the layer of glaze was substantially increased. In consequence the glaze, which did not join in the expansion of the body, was ruptured. Such irregular heating of the tiles must lead to the formation of crazes even when the expansion coefficient of the glaze and body are equally great.

REFRACTORY MATERIALS UNDER LOAD.—(*Amer. Soc. for Testing Materials, Preprint of Report of Committee C-8 on Refractories*, 1918). A larger furnace is recommended for use, similar to R. J. Montgomery's furnace (*Met. and Chem. Engineering*, 18, 18, 1918). The rate of heating shall be according to a given table and time temperature curves, which give the rate and time of heating suggested for different grades of material. The table gives as the temperatures (in degrees C.) to be attained at the end of each 15 minutes by silica as 40, 80, 140, 200, 260, 290, 300, 310, 320, 385, 490, 590, 695, 800, 900, 1,000 (4 hours), 1,100, 1,200, 1,250, 1,300, 1,350, 1,380, 1,410, 1,440, 1,470, 1,500, 1,500, 1,500, 1,500, 1,500, 1,500, 1,500 (8 hours). For fireclay the temperatures at 15 minutes, 30, 45 and 1 hour are to be 160, 280, 400, 500, after which they vary. For heavy duty the temperatures run on 620, 720, 815, 900, 980, 1,045, 1,100, 1,150 (3 hours), 1,195, 1,235, 1,270, 1,300, 1,330, 1,350, 1,350, 1,350, 1,350, 1,350, 1,350, 1,350 (6 hours). For moderate duty, 595, 685, 770, 850, 920, 990, 1,050, 1,100 (3 hours), 1,145, 1,185, 1,220, 1,250, 1,275, 1,300, 1,300, 1,300, 1,300, 1,300, 1,300, 1,300 (6 hours). For light duty, 570, 640, 700, 755, 810, 860, 905, 950 (3 hours), 985, 1,020, 1,050, 1,075, 1,090, 1,100, 1,100, 1,100, 1,100, 1,100, 1,100, 1,100 (6 hours).

NECESSITY FOR INSPECTION AND TESTING OF REFRACTORY BRICKS.—C. E. Nesbitt and M. L. Bell (*Amer. Soc. for Testing Materials, Preprint*, 1918). Attention is called to the want of suitable specifications for refractory bricks, which is mainly due to the methods and tests devised being inapplicable for commercial inspection.

Specifications for bricks should cover only such properties as are essential for some particular purpose. Thus for the iron and steel industry the most important qualities of bricks can be satisfactorily determined by a few simple tests; silica bricks, which are not usually exposed to the action of slag, only need a spalling test and a hot crushing test; clay bricks should be subjected to load, spalling, and slagging tests; these tests cover the qualities the bricks must possess to give good service. Of course bricks which are cracked or

warped, badly moulded, off-size, or badly burned should be looked for and rejected.

The irregularities met with in commercial bricks are indicated by the results of numerous tests. Spalling tests on five successive consignments of the same brand of silica bricks showed that though the general average spalling loss was about 25 per cent., it varied in one consignment from 11·72 to 40·80, and in another from 13·39 to 42·27. Such variations are ascribed to lack of uniformity in grinding, moulding, and general workmanship. Crushing tests of apparently good bricks selected from two brands of clay bricks and four brands of silica bricks also showed very discordant results. The authors consider the load or ball impression test more suitable for clay bricks than the hot crushing test. Variations in slag penetration were also considerable, being largely governed by lack of uniform structure, due to lack of uniform grinding, moulding and burning.

It is suggested that inspection at the factory would eliminate all bricks irregular in shape, off-size, fire cracked, badly moulded, and of poor general appearance. To secure greater uniformity the consumer must adopt specifications for bricks with a view to guard against accepting bad bricks, not to reject good ones.

POROSITY AND PERMANENT VOLUME CHANGES IN REFRACTORIES.—(*Amer. Soc. for Testing Material*, *Preprint of Report of Committee C-8 on Refractories*, 1918). Proposed tentative method for determining porosity and permanent volume changes. Sample to consist of at least seven standard size bricks, from which test specimens $2\frac{1}{2} \times 2\frac{1}{2} \times 1\frac{1}{4}$ inch shall be cut so as to remove original surfaces of the bricks. In all, 35 test specimens are required for each kind of brick, 5 for each of the seven heat treatments. Test specimens to be crushed or washed free from dust, and marked (say with a 5 per cent. cobalt-kaolin mixture).

The dried specimens, after determination of volumes and porosity, shall be heated as rapidly as possible with even distribution of heat to 1,200° C., the temperature being then further raised 30° per hour, and samples drawn at each 50° from 1,200° to 1,500°. If practicable it is best to burn to each temperature separately, the kiln being sealed and left to cool by radiation. Otherwise the five test specimens from each temperature increment should be at once covered with hot sand, or placed in another furnace and kept at about 500° until all have been withdrawn, and then cooled by radiation only with the furnace sealed.

For porosity, etc., the clean dried pieces are to be weighed (D). The specimens are next to be placed in kerosene of known density (δ) under a vacuum of 24 inches for 4 hours at 25° C. and cooled to room temperature while immersed. When cool, each test specimen to be weighed suspended in kerosene at 25° C. to determine its "suspended weight" (S) in grams. The "saturated weight" (W) to be obtained immediately after the suspended weight, by drying lightly with a kerosene-moistened towel to remove excess of kerosene and then weighing in air.

The *Exterior Volume* (V) in c.c. of each test specimen is obtained by subtracting the suspended weight (S) from the saturated weight (W) and dividing by the density (δ) of the kerosene. Thus: $V=(W-S)/\delta$. (1)

The *Actual Volume of Open Pores* (V_1), in c.c., is obtained by subtracting dry weight (D) from saturated weight (W), and dividing by density (δ) of the kerosene. Thus: $V_1=(W-D)/\delta$. (2)

The *Apparent Specific Gravity* (T'_1) of that portion of the specimen which is impervious to liquid is obtained by dividing the dry weight by the difference between the dry and suspended weights, and multiplying by the density of the kerosene. Thus: $T_1=(D \times \delta)/(D-S)$. (3)

The *True Specific Gravity* (T') of the wholly solid or burned clay portion is obtained by crushing a portion of the dried test specimen to 120-mesh powder and determining the displacement at 25° C. under 24 inches vacuum, of a 20-g. sample in a 50 c.c. straight-wall pyknometer, using kerosene, and correcting for density of the kerosene.

The *Volume of Sealed Pores* (V_2) in c.c. is obtained by subtracting the quotient of dry weight (D) divided by true specific gravity (T) from the volume of the impervious portion of the test specimen; or $V_2=(D-S)/\delta-D/T$. (4)

The *Volume Shrinkage* is obtained by subtracting the volumes, or by subtracting the values of $(W-S)\times\delta/S$, before and after the heat treatment.

To show progressive changes in the several volumes, refer all volumes back to the original exterior volume of the test specimen as 100. This is done by multiplying all volumes by $100/V$, in which V is the exterior volume of the test specimen prior to the heat treatment.

The volume data should be determined for each test specimen and multiplied by the above factor to reduce all volumes for each test specimen to terms of 100 original exterior volumes of that test specimen before the average of the five for each heat treatment is calculated.

SILICA CEMENT.—R. J. Montgomery (*Amer. Soc. for Testing Materials, Preprint*, 1918). Refers to the cement laid between the silica bricks or shapes used in constructing furnaces. The silica cement at present used is a mixture of ground ganister rock and clay, the latter being added to make the material easily workable with a trowel. Instead of freshly ground ganister rock, discarded green bricks or burned bats may be used. The clay content is usually from 15 to 35 per cent., and the proportion of ganister rock to bats is one to one. When green bricks are used, it is generally instead of the ganister rock.

At operating temperatures the ganister or green brick will expand more than the burned bats, through quartz changing to cristobalite, but the question of proportions has not been investigated to any extent.

Clay remedies the want of plasticity but lowers fusion point and increases shrinkage. The refractoriness to establish is such as will stand the maximum furnace temperature without excessive softening and shrinkage, while being plastic enough for the bricks to be properly laid.

From analyses of 27 commercial cements it appears that they contained 83·30 to 94·90 per cent. silica (only 6 of them below 90 per cent., and only one below 87 per cent.), 1·03 to 11·68 per cent. alumina, and 2·04 to 5·97 per cent. of other substances, while the fusion points ranged between cones 26 and 32.

Finer grinding increases plasticity, but if too fine it results in the appearance of vertical parting cracks in the joints, causing leakage. Extreme fineness also tends to increase the drying and burning shrinkage.

Drying shrinkage will vary from 0·5 to 2·0 per cent., depending upon the fineness of the grinding and the proportion of clay. The burning shrinkage is low until about cone 13, but above this it increases very rapidly, and will depend as much on the base fluxes present as on the alumina content. In the case of three samples, one showed expansion 0·5 per cent. at cone 1, 0·4 at cone 8, 0·3 at cone 13, and 0·4 shrinkage at cone 20, a second showed no change at cone 13, and 3·8 per cent. shrinkage at cone 20, while the third showed no change up to cone 8, 0·5 shrinkage at cone 13, and 6·1 shrinkage at cone 20. There is a tendency for silica rather low in clay to show a small expansion (due to silica) at the lower cones.

Porosity varies from about 30—35 per cent. at cone 1 to 15—30 per cent. at cone 20, according to the composition of the cement.

Apparent Specific Gravity varies from 2·40—2·45 at cone 1 to 2·20—2·38 at cone 20, according to composition.

Hardness of a cement tested increased with temperature up to 2,800° F. (1,538° C.)

Crushing Strength of the same cement was quite low up to 1,600° F. (871° C.) and then increased rapidly, reaching a maximum at 2,400° F. (1,316° C.). The cement will easily carry the load in a furnace at all temperatures within its working limit.

Safe Operating Temperature. Three cements made into bricks $9\times2\frac{1}{2}\times2\frac{1}{2}$, and placed on end, were heated to about their melting points (cones 31, 30 and $28\frac{1}{2}$ respectively) and held for 24 hours. The cone 31 cement melted very slowly at 2,800° F. (1,538° C.) and slumped under its own weight, being too

soft for a cement. It stood at 2,700° F. (1,483° C.) without showing any tendency to deform. The cone 30 cement softened badly as 2,800° F. (1,538° C.) slumping to the bottom of the furnace under its own weight. At 2,700° F. (1,483° C.) it showed no tendency to deform after 24 hours. The cone 28½ cement slumped to the bottom of the furnace under its own weight at 2,700° F. (1,483° C.) but held 24 hours at 2,600° F. (1,427° C.) without softening.

Testing Silica Cement. Complete information would be given by analysis, fusion cone, sieve test, drying shrinkage, and burning tests at several cones (as 1, 8, 13, and 20) to determine burning shrinkage, total shrinkage, porosity, and apparent specific gravity.

For control work these tests may be narrowed down. A very good way to compare the burning behaviour of two cements is to make a compound test bar about 1½ by 1¼ by 5 inches long, the lower ¾ inch of a standard cement and the upper ¾ inch of the cement to be tested, and burning to the desired temperature. The joint between the two portions should be well worked by roughening the surface of the lower layer before the upper one is put on. The appearance of the bars after heating will show the difference in expansion and contraction. By changing the composition the test batch can be made to agree with the standard.

MAGNESITE.—F. Hamilton (*Mineral Foote-Notes*, Jan., 1918). Relates to occurrences and applications. California magnesite is mostly comparatively pure, and is usually a white, fine-grained rock, much like the magnesite from Greece. Washington magnesite resembles dolomite and some crystalline limestones in appearance, the colour being light to dark grey or pink.

The chief uses at present are in refractory linings for basic open hearth steel furnaces, copper reverberatories and converters, bullion and other metallurgical furnaces; in the manufacture of paper from wood pulp; and in structural work, for flooring, wainscotting, tiling, sanitary kitchen and hospital finishing, etc. In connection with building work it has proved particularly efficient as a flooring for steel railroad coaches, on account of having greater elasticity and resilience than Portland cement. For refractory purposes the magnesite is "dead-burned"—*i.e.*, all or practically all of the CO_2 is expelled from it. For cement purposes it is left "caustic"—with from 5 to 10 per cent. of CO_2. When dry caustic magnesite is mixed with magnesium chloride solution in proper proportions a very strong cement is produced, known as oxychloride or Sorel cement. The fillers used for this cement may be 10 to 40 per cent. of the whole, and commonly consist of ground marble, sand, sawdust, cork, asbestos, or other materials. The finely ground calcined magnesite is packed in paper-lined casks, barrels, or boxes, and should be used within a few weeks after being opened.

A coating of crushed magnesite is laid on hearths used for heating steel stock for rolling, to prevent the scale formed from attacking the firebrick of the hearth.

ZIRCONIUM AND RARE-EARTH MINERALS.—W. T. Schaller (*Mineral Foote-Notes*, March, 1918). Reference is made to the mode of occurrence of zircon and of baddeleyite (also known as brazilite and jacupirangite), which latter has been found in quantity only in Brazil, though also known to occur in Ceylon, Sweden, Italy and Montana. Zircon occurs in quantity in some of the pegmatites of North Carolina.

In the trade baddeleyite implies the variety in distinct crystals, and brazilite the fibrous, botryoidal or columnar forms. The trade name zirkite is used for the commercial ore of zirconia, a mixture of baddeleyite or brazilite, zircon, and a supposed new unnamed zirconium silicate. Zirkite contains from about 70 to 94 per cent. zirconia as shown by the following analyses (1 to 11):

	1	2	3	4	5	6	7
ZrO_2	93·18	81·75	86·57	85·93	82·00	85·01	71·88
SiO_2	1·94	15·49	2·50	9·35	11·38	9·63	25·31
TiO_2	0·69	0·50	1·43	1·84	0·36	1·52	0·63
Fe_2O_3	2·76	1·06	5·29	1·93	2·08	3·57	0·43
Al_2O_3	0·64	0·85	1·00	0·36	0·62	—	0·15
MnO	Trace	Trace	—	—	—	—	—
H_2O	0·47	0·63	3·32	1·56	3·35	—	1·56
	99·68	100·28	100·11	100·97	99·79	99·73	99·96

	8	9	10	11	12	13	14
ZrO_2	94·12	88·40	74·48	68·93	97·19	98·90	96·52
SiO_2	2·41	5·89	14·08	26·30	0·48	0·19	0·70
TiO_2	0·98	3·12	1·35	0·60	0·48	—	—
Fe_2O_3	3·22	4·07	10·26	3·59	0·92	0·82	0·41
Al_2O_3	—	—	—	—	0·40	—	0·43
MnO	—	—	—	—	Trace	—	—
H_2O	—	—	—	0·80	0·38	0·28	0·39
	100·73	101·48	100·17	100·22	—	100·25	99·52

. Slate-grey fava (waterworn pebble resembling a bean). Sp. gr. 5·245. . Light-brown fava. Sp. gr. 4·850. 3—6. Hard lump ore. 7. Grey porous re. 8. Glassy variety. 9. Stony variety. 10. Pebbles. 11. Commercial ariety. 12—14. Purer samples of baddeleyite. 13 contains 0·06 of CaO ncluded in the total but not shown in the table, and 14 contains 0·55 CaO, ·10 MgO and 0·42 alkalies. 12. Botryoidal, from Brazil. Sp. gr. 5·533. 3. From Ceylon. Sp. gr. 5·72 to 6·025. 14. From Jacupiranga, Brazil. p. gr. 5·006.

The Brazilian deposits of zirconia are in the Caldas region, about 130 miles orth of the city Sao Paulo, on a mountainous plateau, and the predominant ock of the plateau is a phonolite. The character of the ore and the formation eems to indicate pneumatolytic agencies as having produced the zirconia eposits. It is suggested that a careful study of the relationship of the large nasses of coarsely crystalline nephelite-syenite in this area, with pronounced egregations of eudialyte, might throw light on the subject.

Zirconia ore can be roughly divided into two classes: (1) Alluvial pebbles f ½ to 3 inches diameter, with usually 90 to 93 per cent. zirconia. These ebbles, known as "favas," sp. gr. 4·8 to 5·2, are found along small stream eds and on the talus slopes of low ridges. (2) Zirconia ore proper, or zirkite anging from a light grey to a blue black, the lighter coloured material ontaining a higher percentage of zirconium silicate; analysis in some cases nows a minimum of 73 per cent. of zirconia. The blue black ore generally ontains 80 to 85 per cent. of zirconia. By careful sorting a uniform grade ith about 80 per cent. is produced. Derby and Lee have shown that this ore, nstead of being identical with baddeleyite, is a mechanical mixture of three inerals—brazilite, zircon, and a new unnamed zirconium silicate with 75 per ent. of zirconia. This new mineral has the same crystal form as zircon (which

contains 67 per cent. ZrO_2), but is readily soluble in HF, while zircon is not affected. The finely powdered mineral on treatment with weak solution of HF leaves minute pyramidal crystals of zircon, the brazilite and new zirconium silicate being dissolved. One or two isolated boulders of the ore weigh 30 tons.

Owing to hardness of the ore, drilling holes for explosives is almost impossible, and for large masses the primitive methods of the emery miners of Naxos are resorted to. A large fire is built against an exposed face, and after burning for several hours, water is thrown upon the heated ore, which cracks and can then be sledged. In some of the deposits the ore occurs as gravel and large pebbles, embedded in a reddish clay matrix resembling boulder clay. The ore is transported many miles to the railway by primitive ox-carts holding about one ton, 20 to 30 oxen being generally required for each cart on the mountain roads.

The deposits have been traced for 15 miles, and from surface indications seem to be of vast extent.

An alloy consisting of 65 per cent. zirconium, 26 per cent. iron, 7·7 per cent. aluminium, and 0·12 titanium is said to be highly resistant to chemicals, to be malleable, and to make good filaments for incandescent lamps.

The name "cooperite" has been given to a new patented alloy of zirconium and nickel. This new alloy, free from iron and carbon, has a bright silvery lustre and is resistant to acids and alkalies. It is stated to be the best known alloy for use in the manufacture of edge tools of all descriptions, especially machine tools for milling cutters and cast tools for lathe and plane use. Milling cutters and intricate tools of all descriptions may be cast from this alloy in such forms as to require only a minor grinding operation for finishing. Cooperite remains liquid for some time before solidifying, and intricate machine tools can be easily cast from this alloy. The heat conductivity is higher than that for other high-speed metals, and the cutting efficiency of the tools is therefore increased. The hardness can be varied by changing the proportions of the constituent metals. An alloy of 2 to 10 per cent. zirconium and the remainder nickel is said to take a fine cutting edge. With 16 to 30 per cent. zirconium, and the rest nickel or cobalt, the hardness is increased. The melting point and tensile strength are decreased as the proportion of zirconium increases. The addition of molybdenum raises the melting point. It is claimed that cooperite is self-hardening, and no tempering or other treatment is necessary except a slight finishing operation.

Zirconia makes a non-poisonous, non-discoloring white paint of permanency and good covering power, which is not affected by hydrogen sulphide, by acids or by alkalies. It has also been applied in making X-ray pictures, and has been suggested as a polishing powder.

The carbide and other compounds, which are very hard, have been suggested as abrasives.

The chief use of zirconium minerals at present is as refractory material, owing to the very small expansion coefficient, the heat-resisting properties, and the resistance to fluxes and slags.

A brief account is also given of cerium, yttrium, lanthanum, and their preparations.

REFRACTORY MATERIAL FOR FURNACE LININGS.—G. W. Patnoe, U.S. Pat. 1,230,430, June 19th, 1917. Magnesian limestone is ground with 2—5 per cent. of argillaceous material containing alumina, silica, and ferric oxide, until practically all will pass a 100-mesh sieve. It is then calcined at 1,425—1,650° to form a dense sintered mass resistant to air and moisture.

REFRACTORY MATERIAL FOR FURNACE LININGS, ETC.—P. R. Hershman, U.S. Pat. 1,227,909, May 29th, 1917. A mixture of 85 parts alumina and about 15 parts carbon is sintered at 1,800—1,900° in a reducing atmosphere (such as combustion gases) without melting, and the sintered product is then mixed with more carbon and with a binder (such as asphaltum), moulded and pressed into shape, and finally heated in a reducing atmosphere to about 1,950°.

DETERIORATION IN SUSPENSION TYPE INSULATORS—J. A. Brundige (*Proc. Amer. Inst. Elec. Eng.*, 36, 391, 1917). The two chief hypotheses for explaining insulator deterioration have been porosity and mechanical cracking through expansion. The author gives the following reasons for believing the latter to be the main case. (1) The conditions inside the metal cap suffice, through temperature expansion, to explain much of the trouble which arises. (2) There is no important evidence to show that electrical stresses have caused trouble. (3) The degree of firing bears no apparent relation, apart from extremes which are easily recognised. (4) As a rule deterioration takes place quickly as from cracks rather than slowly as from gradual absorption of moisture. (5) Examination of condemned insulators has nearly always revealed cracks of more or less long standing.

REFRACTORY BRICKS.—R. H. Youngman, U.S. Pat. 1,231,684, July 3rd, 1917. Bricks for building furnaces or kilns are made of calcined bauxite mixed with about 7 per cent. of magnesite and 1·5 per cent. of chromite, burned at about 1,500°.

SEPARATION OF CLAY AND KAOLIN FROM SLIME.—B. Schwerin, U.S. Pat. 1,234,457, July 24th, 1917. Clay or kaolin with admixed slime is suspended in water and left to settle. The dispersion of the materials and amount of water used for elutriation are regulated so that fractional sedimentation takes place, the products being a sediment of slime nearly free from kaolin (or clay), and a kaolin (or clay) sediment containing not more than 30 per cent. of water.

THE ACTION OF IRON OXIDE ON SILICA.—H. Le Chatelier and B. Bogitch (*Comptes rendus*, 166, 764, 1918). The temperature necessary for tapping steel is about 1,650°; the fusing point of silica bricks seldom reaches 1,750°. The slightest deviations of temperature suffice to cause either a bad tapping of steel or melting of the furnace. The difficulty of management of the heat is further increased by the action of the iron ore dust supplied at the melting zone to hasten the refining. These dusts attack the arch and facilitate its fusion. The experiments of the authors agreed absolutely with those of M. Renegade (*Comptes rendus*, 166, 779, 1918), and complete them on several points. There is nothing to be added to his very exact description of the different parts of a used brick. A. Grey zone, having undergone more or less complete fusion, and the cristobalite being partially and irregularly transformed into tridymite. B. Blackish brown zone, appearing homogeneous, composed of large crystals of tridymite regularly scattered in the midst of a black ferruginous flux. C. Zone strewed with white specks formed by the largest fragments of the quartzose rock employed in the manufacture of the brick, which have not yet entirely disappeared through recrystallization. The quartz has been transformed into very fine tridymite, but the original contour has not yet completely disappeared. D. Shows grains the centre of which consists of cristobalite, this being surrounded by very fine tridymite.

M. Renegade joins with zone C regions with a very dark groundmass, identical with the mass of zone B, and regions of clear yellow ground, in which the microscope shows between the silica grains a transparent glass, scarcely yellowish, and so very little ferruginous. In the author's opinion this part of the brick is better considered as forming a fourth zone (D), for it differs entirely from the preceding by its chemical composition.

	Brick fused prematurely, impregnated to 9 cms. height.			Brick which had been long in use, impregnated to 18 cms. height.		
	Sulphates	Fe_2O_3	CaO	Sulphates	Fe_2O_3	CaO
Original brick ..	10·5	1	2	8·5	1·5	1
Zone C	29·5	4·5	5	22	5·0	1·5
Zone B	29·5	4·5	5	26	6·5	2
Zone A	15	3·5	1·5	18	4·5	1·5

About 0·5 of Al_2O_3 is included in the figures given for Fe_2O_3. These analyses indicate two equally important results pointed out by M. Renegade: (1) The grey zone, heated directly by the flame and exposed to the action of ferruginous dust is less charged with basic oxides than the upper layers, more distant from the furnace atmosphere. (2) In the brown and clear yellow zones there is a great increase in the lime, relatively greater in the brick which fused most rapidly. The authors have studied these two phenomena experimentally in the laboratory.

The penetration of iron oxide into the interior of the brick takes place by capillary ascent. By placing on a piece of brick impregnated with iron a paste of similar brick, but non-ferruginous, and heating for an hour at 1,600°, it was ascertained that coloration due to iron was raised to a height of about 5 mms. into the new brick. This penetration of iron oxide is much more active in the midst of a reducing agent.

A lozenge of 1 grm. compressed oxide of iron, placed on a silica brick and heated to 1,200°, induced the formation in the brick of a cavity having exactly the diameter and the volume of the lozenge of oxide. The iron silicate formed was diffused below into the body of the brick. The same experiment under oxidizing conditions gives no penetration of iron until 1,400°, the lozenge remaining intact on the surface of the brick.

The reduction of the proportion of basic oxide in the part heated directly by the flame, accounts for what the brick contracts, diminishes porosity, expelling the ferruginous dross which rises into less hot regions. A ferruginous brick, cut in the region B of a used brick, took a contraction of 0·5 per cent. after one hour's heating at 1,600°. The original brick, non-ferruginous, heated in the same conditions, had swelled 5 per cent. in consequence of the transformation of quartz into silica of lower density. This contraction increases with the time, at the same time that crystals of tridymite continue to increase in size.

This contraction is very easily proved on bricks in service, at least so long as they have not been superficially fused by overburning. They present on their outer surface a little slab, the shape of which is that of the brick, but with dimensions 10 per cent. lower. This slab ends by becoming detached and falling, thus producing wear of the brick, but a very slow wear. There has been then only semi-fusion. In case of complete fusion in consequence of an unlucky flash the brick runs, giving stalactites; these remain suspended from the arch, if the heating has been reduced in time; if not, the brick soon disappears completely, causing downfall of the arch.

Metallic iron, placed on the surface of a brick, produces deep holes in it, in reducing atmosphere as well as in oxidizing atmosphere, because in all these cases the first stage of oxidation of the iron is the protoxide which combines with the silica. In this way are destroyed the walls which receive little drops of fused iron projected by ebullition of the mass of steel during refining and swept away by the gaseous current. These little drops are too heavy to be lifted up to the arch.

Impoverishment in lime of the superficial layer and enrichment of the upper layers is produced by a phenomenon analogous to clarification (decolouring). The silicates of iron, rising by capillarity into the brick, chase before them the alumino-silicates of lime pre-existing in the brick and serving it as flux in the first heating. The same phenomenon was realised in the laboratory by taking a rod cut in a new brick, placing it vertically on a mass of iron oxide and heating to 1,600°. After an hour the distribution of the lime was the following:

Original brick	2·07 per cent.
Limit of ascent of the iron oxide ...	2·45 ,,
Part in contact with free oxide ...	0·88 ,,

The height of ascent of iron oxide was only 2 cms. When the heating, instead of lasting only an hour, is prolonged for weeks and months, the distance to which the iron oxide penetrates is greater, and in consequence the proportion of the brick laved by the iron oxide being more important, the enrichment in lime of the upper regions is greater. This enrichment is the more important as the destruction of the brick advances more rapidly, because the size of each

zone being then less the relative concentration should be stronger there. This conclusion conforms well to the results of experiments given above. This enrichment of the middle regions in lime has very great practical importance. A mass including 5 per cent. of lime, like zone C of the first brick studied, has its melting point near 1,600°, whilst zone A of the same brick has a melting point about 1,700°. If in consequence of an accidental flash of the fire the temperature 1,700° should be exceeded momentarily, and if the superficial layer be melted, the following layer, being suddenly brought into contact with the flame, before capillarity has had time to impoverish it in basic oxides, necessarily melts in its turn. In a few minutes a brick can thus lose half its height.

A silica brick impregnated with iron oxide is then in a kind of unstable equilibrium; a flash of the fire very easily suffices to produce a disaster. This is one of the reasons which render the management of a steel furnace so delicate an operation.

COLOUR FROM FERRIC OXIDE AND ALUMINA (IN BRICKS).—F. H. Scheetz (*J. Phys. Chem.*, 21, 570, 1917). The author concluded that a buff colour would result from precipitation of a little $Fe(OH)_2$ with much $Al(OH)_3$. Thus addition of $Ca(OH)_2$ to a mixture of $FeSO_4$ and $Al_2(SO_4)_3$ gave a precipitate which was buff even when heated to 1,000°, provided the Fe_2O_3 did not exceed 8 per cent. of the $Fe_2O_3+Al_2O_3$. Precipitating the solutions by NaOH or Na_2CO_3 did not give a uniform buff even with only 2 per cent. of Fe_2O_3.

ZINC REFRACTORIES.—C. P. Fiske (*Bull. Amer. Inst. Mining Eng.*, p. 1,719, 1917). The pottery of the N.J. Zinc Co., at Palmerton, makes 3 kinds of refractories, spelter muffles and retorts, spelter condensers, and firebricks. St. Louis clay is used as bond clay, and new calcined flint clay from the district of Clearfield, Pa., has been found better for grog than old bats, etc. Promising trials have also been obtained by using broken pottery saggars. Theoretically a uniformly blended one-material body (natural, or artifically blended) should be better than a mixture of bond clay and flint clay, but this has not been attained yet. For spelter muffles and retorts some chipped petroleum coke—a typical analysis of which is 89·00 fixed carbon, 0·47 water, 8·62 other volatile matter, 1·14 sulphur, and 1·83 ash—is used in the mixture, which is rotted for three or four weeks, in dark storage pits. Thorough rotting or ageing renders weathering unnecessary. Though laboratory tests are not regarded as conclusive, tests are made for refractoriness at 1,630°, tensile strength and shrinkage after drying at 110°, and also tensile strength, shrinkage and porosity at 1,300°. Chemical analysis is not often made. Probably tensile strength is the most valuable test. Grog is similarly tested, mixed with standard bond clay. The use of coke was suggested by its successful adoption abroad, and exhaustive tests of its value have been commenced. No lubricating effect of the coke has been observed in pressing. The grog is screened through 6-mesh and the bond clay through 8-mesh. The proportion of different sizes of grog is important, for laboratory tests showed variations up to 50 per cent. in tensile strength A commercial sizing closely approximating to the theoretical is 25 per cent. 10—16 mesh, 25 per cent. 16—30 mesh, and 50 per cent. through 30 mesh. The mixtures at present in use are for:—(1) *Spelter muffles and retorts*: 145 St Louis clay, 150 calcined flint clay, 19 lb. pulverized coke, mixed with 10 to 11 per cent. water. (2) *Condensers*: 150 St. Louis clay, 150 lb. grog, mixed with 14—15 per cent. water. It appears that rotting too long may be as bad as not rotting long enough. Thus the tensile strength of St. Louis clay (after drying at 110°) following rotting for 1 day, 1 week, 2, 3, and 4 weeks respectively was 67·5, 83, 93, 67, and 39 lb. per square inch.

The grinding, sieving, mixing, pugging, and pressing are described in detail. The open work floors of the drying rooms are underlaid by two independent sets of steam pipes, and running along near the top of each room is a main channel with adjustable openings for conveying moisture to a stack. The drying goes on at ordinary temperatures for 2 or 3 weeks, the whole period for drying amounting to 4 months, and the temperature being gradually raised

to a maximum of 120—125° F. The manufacture of condensers and of bricks is also described.

QUARTZ SUITABLE FOR HIGHLY REFRACTORY BRICKS.—S. Franchi (*Ind. Chim. min. met.*, 4, 212, 1917). Bondolfi (*Met. italiana*, 9, 1917) showed that the German silica bricks sold under the name "Stella," which are reputed to be the best in the world, are better than the other German, American, English, Russian, and French bricks examined, lasting for 400 to 1,000 heats in the steel furnace, whereas the others average 250 heats. The "Stella" bricks are made from a Tertiary quartzite which is associated with lignite beds. The crushed quartzite is bonded by milk of lime, and the quality of the bricks is not due to any superiority of manufacture, for other quartzites of similar origin, refractoriness, and analyses (as reported) yield very inferior bricks. The best material is yellowish in tint, and microscopic examination shows it to be made up of quartz fragments bonded by micro-crystalline quartzite (though it has been described as amorphous). The yellowish colour is due to inclusions of rutile in the binder. The quartzite contains not more than 1·1 per cent. of titanium dioxide, which has never been reported in the German analyses, and the superiority of the quartzite apparently depends on these inclusions. After firing, the inclusions could not be investigated microscopically owing to difficulty in preparing thin sections. Further study is necessary to determine the influence of the inclusions. The value of the English Dinas bricks is probably not dependent on the material being of Carboniferous origin, hence raw materials may be sought in other formations in Italy.

ZIRCONIA, A NEW REFRACTORY.—H. C. Meyer (*Met. Chem. Eng.*, 12, 791, 1914). Only two known minerals occur in sufficient quantity for commercial sources of zirconium and its compounds, zircon (zirconium silicate) and natural zirconia (zirconium oxide). The natural zirconia carries about 84 per cent. of the pure oxide, with about 8 per cent. silica and 3 per cent. iron oxide. The best known method for extraction of the pure oxide is to fuse the natural substance with sodium carbonate or hydroxide to form sodium zirconate, which on being leached is hydrolyzed, producing soluble sodium silicate and insoluble zirconium hydroxide. The well-washed precipitate can be readily converted into soluble salts by treating with any of the strong mineral acids.

Refined zirconia is a pure white substance of density about 5 and melting point 3,000° C., according to Weiss. The first important use for the oxide was to replace lime in the cylinder used for the Drummond or lime-light. The zirconia gave more intense illumination, and (unlike lime) was absolutely unaffected by moisture or any of the atmospheric gases. In 1880 it was used for incandescent gas mantles, but for this purpose it has been almost entirely replaced by the oxide of thorium, which gives the same results at a much lower temperature. In 1897 pure zirconia was used in the Nernst lamp, which consists essentially of small rods or "glowers" composed of magnesia, zirconia and yttria. By a heating device, the glower is raised to 634° C., when the electric current begins to flow and raises the oxides to incandescence.

The high melting point, low coefficient of expansion, and low thermal conductivity of zirconia, make it apparently the ideal lining for electric furnaces of the arc type. Careful tests have shown that natural zirconia is eminently fitted for such work and has only a slightly lower efficiency than the much more costly pure oxide. Heat-resisting ware in the form of crucibles, muffles, pyrometer tubes, combustion boats, and resistance cores for electric furnaces, can be made from pure zirconia mixed with 3 to 10 per cent. magnesia, using starch, phosphoric acid, glycerine or borates as binders. After drying, and firing at 2,000° to 2,300° C., the ware is practically impervious to liquids, and is not affected by strong acids or alkali fusion mixtures. From very sudden changes of temperature such as plunging a red-hot zirconia crucible in water, there is not the slightest danger of fracture. The fusing point of tungsten alloys, and the boiling point of pure iron, have been successfully determined in zirconia crucibles. An iron-free zirconia can be prepared at a low cost

according to German patent No. 262,009. The pure zirconia mixed with enough sodium silicate or phosphoric acid to form a plastic mass, affords a cement or lute capable of withstanding the severe temperatures of electric furnaces of either the resistance or arc type. According to a private communication, actual working tests made on a Martin-Siemens furnace in a steel works at Remscheider, Germany, showed that after 4 months of continuous operation at high temperatures the zirconia-lined hearth was still in good condition and would serve at least 4 months longer before renewal. Careful statistics compiled from these tests show a saving of 50 per cent. in actual maintenance costs in favour of the zirconia lining over the refractory lining generally used, without considering the increased production and higher efficiency. It has been demonstrated in actual practice that, owing to the low thermal conductivity of zirconia (about half that of ordinary firebrick), a 2 inch lining is equivalent to 4 inches of chamotte. Gaseous or molten fluorides, and also bisulphates, attack it.

Zirconia should be useful as a protective coat or paint for ordinary firebricks exposed to the destructive action of acid fumes or slags. A suitable bonding medium for such a purpose might be found in a weak solution of water glass or sodium silicate.

In lining furnaces or other metallurgical apparatus, natural zirconia can be mixed with water-free tar as a binder, in which case wooden forms are generally used. These are allowed to remain in place and are consumed during the initial heat. The temperature should be raised very slowly at first to eliminate the volatile products in the tar, after which a temperature of at least 1,400° C. must be maintained for about 48 hours. Natural zirconia begins to fuse at about 1,800° C., and at 2,000° C. there is a noticeable volatilization of silica and other impurities.

In the manufacture of natural zirconia bricks, muffles, crucibles and small articles of refractory ware, about 2 per cent. of air-slaked lime as a binder has been used with success. In practice, a batch composed of 75 per cent. 100-mesh zirconia, 23 per cent. of 10-mesh, and 2 per cent. of slaked lime, is worked into a plastic mass with a 3 per cent. solution of 38° Bé. sodium silicate. The bricks or ware are then pressed from this and allowed to thoroughly dry in a warm atmosphere. Subsequent treatment is the same as for ordinary refractories, except that for proper vitrification a temperature of at least 1,400° C. is necessary

Where imperviousness is not required the finished product might perhaps be lightened by mixing with the material sawdust, cork dust, or ammonium salts.

The cost of zirconia is considerably lower than that of certain artificial refractories produced in the electric furnace.

FURTHER NOTES ON THE REFRACTORY PROPERTIES OF ZIRCONIA.—H. C. Meyer (*Met. Chem. Eng.*, 13, 263, 1915). The mean of three analyses of an average sample of natural zirconia showed 84·10 ZrO_2, 7·74 SiO_2, 3·10 Fe_2O_3, 1·21 TiO_2, 0·66 Al_2O_3, and 2·72 loss on ignition (mainly moisture with a little organic matter). Total 99·53.

Heat Tests on Zirconia.—G. T. Stowe found that an ore containing 84 per cent. ZrO_2, ground to 100-mesh and mixed with water, moulded easily into cones which kept their shape with little warpage or shrinkage when burned to about cone 35 (1,830° C.). These tests on cooling showed a slightly vitrified material with smooth fine-grained surface. Zirconia mixed with a 5 and 15 per cent. mixture of Bens Creek clay (in view of finding a suitable bonding material), and heated to beyond cone 31 (1,750° C.) showed the 15 per cent. test to be in fair shape, that is, slightly vitrified, cracked and coarser grained, while the 5 per cent. test was in good shape with a fine finish and very little shrinkage or warpage. A mixture of 5 and 15 per cent. Warrior Ridge clay with the zirconia heated to about cone 32 (1,170° C.) showed the 5 per cent. mixture to be in excellent shape with a clean cone standing at the end of the test. The 15 per cent. mixture did not hold up quite as well at the same heat. A mixture of 98 per cent. 100-mesh zirconia and 2 per cent. slaked lime

worked up with water showed a fusion point of about cone 30 (1,730° C.), and lost its shape by warping at least five cones before the mixtures with clay. The mixtures on the whole were easily moulded. The pure zirconia test cones seemed to have some plastic properties and held together very well, making a clean and sharp-edged cone. Of all the tests made, the 5 per cent. mixture of Warrior Ridge clay with the zirconia seemed to make the best bond, producing the best looking samples before and after burning, the pure zirconia tests excepted, and those only as to heat tests.

Fire Shrinkage.—The author made briquettes 36 × 20 × 5 mm., which after well drying, were burned in a gas muffle at about 1,427° C. They consisted of (1) pure zirconia (99 per cent.); (2) wet ground zirconia (84 per cent.), very finely divided; (3) zirconia (95 per cent.), obtained from (2) by removal of most of the silica and nearly all the iron; (4) 93 grams of (3) with 7 grams Dry Branch kaolin. (5) 60 grams zirconia, 80-mesh (84 per cent. ZrO_2) and 40 grams wet ground zirconia (2). (1) gave a sticky mass when mixed with water and was quite soft after drying. After burning it was still soft and could be readily scratched with the nail. (2) was readily moulded into shape, and after firing was extremely dense and of flint-like hardness; several briquettes heated to redness showed no cracks after plunging one end into water. (3) after firing was very dense and extremely hard. (4) showed the bad effect of even a small percentage of a very refractory china clay, Dry Branch kaolin being a pure white, washed clay, having a fusing point above 1,790° C. (5) after firing appeared rather coarse and porous, but possessed considerable tensile strength. The shrinkage was only 3 per cent., whereas (4) showed 12 per cent. shrinkage, and (1), (2), and (3), each 9 per cent.

Binder.—R. C. Gosrow made small briquettes $1\frac{1}{4} \times 1\frac{1}{4} \times 4$inches in a steel mould, using strong pressure. The five tests included: (1) Zirconia powder, bonded by magnesium chloride solution (26·5° Bé.) to a stiff mud; dried 5 days at 100° C., then 8 hours at 150° C., next heated gradually to bright red and exposed to 1,600° C. in electric arc furnace for two hours. The test-piece showed no fusion, the corners being sharp and hard, it scratched glass, the shrinkage was slight and density great, ferrous oxide and iron adhered in molten condition, the former showing corrosion; it was difficult to crack with a bricklayer's hammer. (2) Equal parts of zirconia powder and dead-burned magnesia, bonded like (1), also dried and heated like (1); fused to dark-coloured spongy mass, evidently owing to iron oxide and silica. (3) Zirconia powder 10, dead-burned magnesia 88, magnesium chloride solution (26·5° Bé.) 2 per cent. Mixed to stiff mud, dried and heated as for (1); product hard, dense, compact, corners sharp and hard, no fusion, no corrosion by ferrous oxide, light brown colour. (4) Zirconia powder bonded by 30° Bé. sodium silicate solution to form stiff mud, dried and heated like (1); no fusion, very hard and dense, interior apparently denser then exterior, slight crack in interior (probably due to moisture). (5) Zirconia powder, bonded by small amount of water in form of vapour, mixed to stiff mud, dried and heated like (1); properties similar to (1), including the same ferrous oxide corrosion. Excepting (2), which fused, the samples showed general corrosion by ferrous oxide in spots, slight shrinkage, no cracking or spalling in temperature changes from 500° C. to 1,600° C., no contortion or deformation at high temperature, precaution necessary in choosing binder, also care required in mixing with other refractories containing impurities (as FeO, SiO_2, etc.), and that zirconia can be used equally with magnesia, and with less cost for linings, etc.

J. R. Adams, under the author's supervision, made further tests, suggested by Gosrow's No. (3), but with water-ground zirconia as binder (preliminary tests indicating that magnesium chloride would be objectionable on a commercial scale). The mixtures used were: 3A, consisting of 45 grams zirconia (ground to pass through 80-mesh screen), 45 grams magnesium oxide (ordinary calcined magnesite), and 10 grams water-ground zirconia, and 3B, consisting of 72, 18, and 10 grams of the same materials respectively. The briquettes were carefully dried, and burned in a small muffle furnace at about 1,427° C. After burning, 3A was brownish yellow, of rather loose texture, but quite resistant to abrasion and of fair tensile strength; the fire shrinkage

was about 8 per cent., and a white hot briquette dropped into water showed no cracks. 3B had much the same appearance as 3A, and fire shrinkage was about the same, though specific gravity was higher. Further tests are being made. The strong objection to the use of the magnesium oxide is its extremely high shrinkage (except when electrically shrunk).

Fireclay Bond.—Zirconia, ground to pass through a 80-mesh screen, was thoroughly mixed in a dry pan with 5 per cent. of Warrior Ridge clay. The mass was slightly moistened and formed into standard-size bricks in the same way as for silica or chromite bricks, and after well drying the bricks were burned in a silica brick kiln at about 1,650° C. The bricks averaged 11¼ lb. each, and softened well below the fusion point of natural zirconia.

A zirconia brick was made a part of one side of the trough of a granular carbon resistance furnace, the rest of the trough being made of magnesite bricks, all being backed up by firebricks. In about half-an-hour after starting, the temperature of the surface of the brick next the carbon resistor was 1,800° C. ± 25°, and it was held between 1,750° and 1,850° C. for 1½ hours. On taking the furnace apart the zirconia brick was just nicely red on the back (2½ in. from the resistor), while the magnesite bricks were much redder. Zirconia has much lower thermal conductivity than magnesite, and probably lower than any other available material that will stand 1,800° C. A slight shrinkage was noticed on the hot face, and the surface of the zirconia brick was slightly pitted and spongy, the spongy layer being about ⅛ in. thick. The magnesite bricks were much more acted upon by the carbon than the zirconia bricks, their surfaces being eaten away uniformly over ⅛ in. Hence, as regards the action of carbon on the hot brick, the zirconia brick appears superior to magnesite, but inferior to carborundum. The brick had not really fused nor flowed of its own weight, yet when picked up with tongs, under gentle pressure, the tongs sank into the hot face of the brick to a depth of ½ in. If the whole brick had reached 1,800° and had been under any pressure (as from overlying bricks in a wall) it would certainly have been pressed out of shape.

Thus 1,800° C. is the upper limit at which this brick (zirconia bonded with Warrior Ridge clay) could be safely used. A brick bonded with water-ground zirconia and free from clay bond, might possibly be stiffer and stand up at higher temperatures.

This particular brick is refractory enough to be classed among the half-dozen highest refractories; as regards shrinking and cracking it is far better than magnesite, though not as good as carborundum. Its behaviour in contact with carbon can probably be controlled.

Zirconia crucibles must be made much thinner than with clay, because of its low thermal conductivity. Its high tensile strength when properly bonded and burned enables this to be done without risk of breakage through handling. Water-ground zirconia might perhaps prove efficient as a lining for graphite crucibles.

SIZE AND QUALITY OF FIREBRICKS.—(*Iron and Steel Institute*, preprint, 1918). A report from the Committee on Blast-furnace Practice. Inquiry was made as to the best thicknesses and other dimensions of lining bricks, and what methods could be recommended for the preservation of linings. Also, whether any advantages accrue from varying the quality of the bricks used in different parts of the furnace.

The size of lining bricks used in many furnaces in the Cleveland district is 4 to 4½ inches thick, from 1 foot 3 inches to 3 feet long, and 12 inches wide. In some cases blocks or lumps 18 by 30 inches are used. It is largely a question of use as to what dimensions are utilised for lining-lumps. Thin bricks have the advantage of probably being better burnt; on the other hand, thick bricks can be made of greater length and are less liable to break before and after being built into the furnace. Two firms in Lincolnshire have used bricks 2½ to 3 inches thick for fifteen years, and are of opinion that the thin bricks are better for furnace lining than the ordinary furnace lumps, for the reason that they are better burnt. The standard sizes used are: Compass: 13½ inches by 5—6 inches by 2½ inches, and 9 inches by 4—4½ inches by 2½ inches. Squares: 13½ inches by 6 inches by 2½ inches, and 9 inches by 4½ inches by 2½ inches.

Practice varies in the use of bricks of different quality in different parts of the furnace. Five firms out of all who replied consider that there is no advantage whatever to be gained in varying the quality of the bricks, provided they are good well-burnt bricks made from a clay of average good analysis. The question is thought to be superfluous, as, according to one opinion, the best firebrick ever made cannot stand up to the temperature in the region of the tuyeres, and whatever money is spent in such refinements as dressing the hearth-lumps is thrown away, as, the moment the furnace starts to melt, it removes the surface of the bricks by fusion and replaces them by scar, which is infinitely more refractory.

Eleven other firms, however, all appear to use bricks of different quality for the upper and lower parts of the furnace. The hearth and bosh are lined with first quality bricks on account of the higher temperatures, and a lower quality, but very hard burnt brick, is taken fcr the upper part, in order to resist the greater erosion, especially where the material shoots off the bell.

The advantages accruing from varying the quality of the bricks in the lining may be summed up as follows: (1) Saving in cost. (2) Best quality bricks, which are most suitable where heat is greatest, are not so well fitted for the top part of the furnace, where a lower quality brick, but better mechanically, is more suitable where a suitable amount of bumping takes place by the lowering of the charges.

For preserving the lining at the top of the furnace, several firms find that a good method is to insert rolled steel protection bars at a point immediately below the gas outlet; the bars being upwards of 25 feet long and 6 inches broad, and $\frac{3}{4}$ inch thick. They are bent over a couple of feet at one end, and are inserted in thebrickwork all round the furnace at the point mentioned, the bars hanging down close to the lining, and forming a shield at a point where damage is likely to be caused by the dropping in of charges, especially if the furnace is being worked low. The practice at another works is to place heavy tapered castings on the tops of and overlapping the brickwork, in order to meet the shock of materials leaving the bell. The furnaces at present blowing have been in operation about four years, and up to now there are no signs whatever of wear.

Trial has also been made with cast-iron plates built in between the courses at the part of the furnace where the material shoots off the bell and strikes the lining, but carbon diffuses into the metal and swells the cast-iron plates, so much so that it raises the level of the platform plates.

Others have found no advantage from protective inner plates or other devices. They obtain specially hard-burnt firebrick blocks for the lining at the top, and special mortar.

In the opinion of one the use of water blocks above the tuyeres for protection of lining is quite unnecessary in a furnace making upwards of 1,000 tons weekly, and in fact, they should be used very sparingly in any furnace, as instances have occurred where rows of blocks have had to be put out of commission owing to the furnaces taking water, and not being able to locate it; and, further, when a block has been found to be leaking, it is often impossible to insert a new one, owing to the lining having settled and fastened the old one in.

In some cases, for the shaft, staggered rows of open circular cast-iron cooling boxes, about 3 feet apart, extending to 30 feet above the bosh, are used. Four of these can be fed by a $\frac{1}{4}$-inch water-pipe, very little water being required. For the bosh, copper plate-coolers from the tuyeres to top of bosh have been employed, the thickness of lining being $22\frac{1}{2}$ inches. A better arrangement is to have copper plate-coolers 3 feet above the tuyeres with 27-inch lining, and water-jacketed to top of bosh with $13\frac{1}{2}$-inch lining. A continuous water-spray is maintained on the jacket.

A firm in the North-Western district finds that the most suitable lining brick is 4 inches by 12 inches wide at the nose by about 18 inches long. To preserve brickwork both the cascade and a modified Sahlin bosh with bronze coolers are used, which can be withdrawn when carbon deposition has taken place.

At the top of the furnace a very hard-burnt brick, higher in iron contents than those for the bosh and well, is used.

The experience of others is that the linings from the hearth up to the bosh should be thin—say, from 12 to 15 inches thick—but with this a water casing must be applied. From the bosh upwards a lining, say 2 feet to 2 feet 6 inches, is desirable, but water might be carried (with advantage) right to the top, and in that case there is no reason why a thin lining should not work satisfactorily.

Another recommends a hearth lining not less than 3 feet plus 6 inches of coke and tar next to the jacket. For the bosh a thickness of 9 inches inside an inverted cone of steel plate. No regular water-cooling, but sprays arranged to meet emergencies. Furnace body, 24 inches, in two concentric circles of blocks 12 inches long by 6 inches thick by about 24 inches wide.

ZIRCONIA.—L. Bradford (*Iron & Coal Trades Review*, 96, 311, 1918). Report of paper read at meeting of Birmingham Metallurgical Society. The ground is largely covered by previous papers and abstracts, but several useful points and references were included. The use of refractory bricks made of (say) bauxite or fireclay and faced with zirconia has been patented in the United States by McKnight and Youngman, and by Herzfeld in Germany. Herzfeld recommends the application of an intermediate coating of a mixture of zirconia and the material forming the body of the brick. Engel, in a U.S. Patent dated April 20th, 1915, specifies 1 to 10 per cent. zirconia to be mixed with fireclay for use in connection with distillation of zinc.

In the course of discussion Mr. H. Edwin Coley (of Coley & Wilbraham, London) said zirconia bricks, zirconium oxide, and pure zirconium salts were being manufactured by his firm, and they were using commercially a method by which bricks were formed without using any binder of lower melting point. The first step in the purification of the ore was the use of nitre cake, as Mr. Bradford had said. They had now a method, discovered only a week ago (in March), by which pure zirconium oxide was produced commercially, and he had a specimen brick with him.

Mr. Bradford said the plastic cement made in America by grinding the zirconia itself in water seemed very suitable as a bonding material.

SAND: ITS OCCURRENCE, PROPERTIES, AND USES.—L. L. Hopkins (*Carnegie Library, Pittsburgh*, 1918). A bibliography based on the contents of the Technology Department of the Carnegie Library. The use of sand in the manufacture of sand-lime brick was dealt with in a former publication of this Library (Brick Manufacture and Bricklaying, 1912), and has not been included in the present list. Sand blasting, sand roads, and some other applications of sand have also been omitted.

DETERIORATION OF FIREBRICKS.—G. Rigg (*J. Ind. Eng. Chem.*, 5, 549, 1913). A discussion of the circumstances which promote deterioration. The author concludes that (assuming equality in other respects) the more compact and close-grained the bricks the greater the resistance to the action of corrosive slags and gases. Spalling of the close-grained bricks results from using unsuitable clay, or from poor workmanship, or both. Close-grained firebricks can be prepared so as to contain a considerable proportion of coarse material, if the grog be carefully sized so that the smaller particles may fill as completely as possible the spaces between the larger pieces.

TEMPERATURE OF FILAMENTS IN INCANDESCENT LAMPS.—Summer (*Electr. World*, 62, 245, 1913). A paper read before the German Lighting Engineering Society relating to a new method for determining the true temperature of the filaments in incandescent lamps. If the total electrical energy supplied to the filament is changed into radiation, it is possible from the Joulean heat to determine the true temperature of a filament of known surface, if the law for total radiation is known for the substance, and if the radiation constant is also known in absolute units. The radiation laws are known exactly for the absolute black body and for bright platinum. In the case of other metals the Aschkinass theory must be employed. The assumptions made in this method are discussed.

COMPARATIVE TESTS OF PORCELAIN LABORATORY WARE.—C. E. Waters (*U.S. Bureau of Standards, Technologic Paper*. No. 105, 1917). The tests were made on dishes (and crucibles, except the Berlin) of Royal Berlin porcelain, "Bavarian" ware, a Japanese brand (marked S.C.P.) and two American porcelains, Herold (Coors) and Guernsey. The tests included sudden cooling, sudden heating, treatment with sodium hydroxide, sodium carbonate, sulphuric acid, fused sodium nitrate, fuesd sodium-nitrate-carbonate mixture, ignition with ferric oxide, and porosity.

In the sudden cooling test each piece was three-fifths filled with paraffin at 100° C., then brought to the desired temperature on a hot plate. It was then floated on water at room temperature. There were no failures on cooling from 200° C., but a number of dishes and crucibles cracked or broke when they were cooled from 225° C.

In the sudden heating test the pieces were placed on a wire triangle and heated in the full flame of a Fletcher burner of the Méker type for 3 minutes, the flame being then removed After 10 seconds the piece was removed with platinum-tipped tongs, being then of the pale straw-yellow colour at which it is ordinarily handled with tongs. In many cases the glaze cracked where touched by the tongs. The Royal Berlin and Japanese wares withstood this test, and also recent samples of Coors ware.

As regards resistance to reagents there was little to choose between the five brands of porcelain tested.

FLOCCULATION.—S. U. Pickering (*Proc. Royal Soc.*, A. 94, 315, 1918). The breaking down of clay soils by frost is largely due to the mechanical disruption of the clods, but a change also occurs in the ultimate particles, which, when agitated with water, are found to sink more rapidly than before. This is due to the shrinking of the individual particles, and their agglomeration into clots. Such a change is the reverse of that occurring in flocculation produced by the addition of acids, etc., where there is an increase in the size of the individual particles.

All bulky hydrated precipitates appear to behave as clay does on freezing, as in the case of three basic copper sulphates, copper hydroxide, ferric hydroxide, and precipitated alumina, which were compared with clay and kaolin.

Freezing and subsequent melting of the watery liquids in which the substances were suspended resulted in all cases in considerable shrinkage (ranging from 40 to 90·3 per cent.), apparently due to dehydration. Such dehydration by freezing exemplifies a chemical combination feebler than that uniting similar molecules in a crystal. It is not a temperature effect, and shrinkage does not occur when there is insufficient water present to allow of crystallization.

With clay where the particles are of very different magnitudes (unlike the hydrated precipitates) freezing reduces the amount of finer particles left in suspension in nearly the same ratio as it reduces the volume of the coarser particles in the sediment.

Rehydration of frozen clay must occur somehow in the field, but by what agency is not apparent, neither frozen clay nor any of the precipitates showing any increase in bulk on being left in water for months; in the case of clay neither boiling nor treating with different strengths of potassium hydroxide solution produces any appreciable effect, and even re-puddling only produces a limited effect, probably due merely to the breaking up of the clots, and not to re-hydration. Repeated air-drying and moistening of the sediment during several weeks produced no greater effect, and mixture with some garden soil during such treatment produced no change.

Previous workers seem to have overlooked the fact that flocculation is accompanied by a large increase in the volume occupied by the particles, as evidenced by the volume of the deposits eventually obtained on subsidence.

A kaolin suspension—containing 20 per cent. of solid, after ignition—was treated with different flocculating solutions of various strengths. The con-

centrations (equivalents per litre) at which flocculation is complete are

0·0003N to 0·001N	$NaOH, KOH, \frac{1}{2}K_2CO_3$
About 0·01N	$H_2CO_3, \frac{1}{2}K_2SO_4, KCl, KNO_3$ (or at 0·0001N)
0·1N to N	$\frac{1}{2}H_2SO_4, HCl, HNO_3$

The equivalent of carbonic acid has been taken as H_2CO_3 because only one of the atoms of hydrogen exists as acid hydroxyl, the other being inoperative. The volumes of the sediments and of the matter in suspension are plotted so as to show the relationship.

The volume occupied by the whole of the solid particles is the property which ought to be represented, but this cannot be determined, and it is not even possible to separate the suspension completely from the sediment; but even in extreme cases the suspended matter can amount to only about 6 per cent. of the total solid present, and a correction for this, in order to convert the observed sediment into volumes occupied by the total solid, would amount to 0·25 c.c. at most, an almost negligible quantity.

As regards acids and salts, the increase in the sediment volumes forms an exact counterpart to the decrease of matter in suspension, the latter becoming nil when the former attains a maximum; where, as in the case of cane sugar, there is no flocculation, there is also no increase in the volume of the sediment. Both phenomena must be attributed to the same cause, and this, apparently, is the combination of the flocculant with the kaolin. An investigation of such combination was possible in the case of acids and alkalies, but only over a limited range. In the case of sulphuric and hydrochloric acids, practically the whole of the flocculant is removed from the liquid, up to the point at which flocculation becomes complete, beyond which there is no more removal; a definite quantitative combination must therefore occur. With soda (NaOH) the results also prove combination to occur up to the point of flocculation, but owing to the strength of the solutions concerned they cannot be extended so as to prove that it becomes complete at this point (0·1 to 1·0N). The determinations show a combination of $100Al_2O_3$, $2SiO_2$ with $0{\cdot}28H_2SO_4$ (0·56 equivalent), with 0·46 HCl, and with 2·2NaOH.

On flocculation the Brownian motion of the particles ceases, and, as this motion is but a consequence of the smallness of the particles, flocculation must increase their size. No swelling of the particles can be observed under the microscope, hence the increase in size must be due to their combination with invisible liquid matter; a layer of liquid round a solid particle would act as a buffer against molecular bombardment, and hence arrest Brownian motion.

The increased volume occupied on subsidence (showing increased size of the particles) is about 200 per cent. in the case of acids (including carbonic acid), and 100 per cent. in the other cases, and could not result from the union of such small proportions of the solute with the kaolin; whatever views be taken as to its condition, the solute is certainly united with a large proportion of water, amounting in dilute solution to several hundred H_2O, and the union of such complex hydrates with the kaolin would quite account for the increase in volume observed.

It is owing to this action of carbon dioxide that samples of clay taken from the same spot at different times are found to vary greatly in suspensibility.

The spheres formed by the solid particles surrounded by liquid molecules would exhibit some surface tension towards the medium; and as in an imperfect emulsion these spheres would tend to coalesce into irregular masses, with the solid particles congregated towards the centre. Hence the appearance of an attraction between the solid particles.

Alterations in the composition of the hydrates as the concentration of the solutions are altered would produce alterations in the sediment volume curves. The reaction of the flocculant with traces of impurity in the kaolin would account for the zero point not always being quite in harmony with the volumes for the weakest solutions.

The changes suffered by the kaolin do not cease when flocculation is complete, for the volume of the sediment decreases, and subsequently increases, on further addition of the flocculant. The decrease is attributable to the

dehydrating action of the solute, partly on the hydrates present, partly on the kaolin itself. The latter with great concentration of the solution always appears grey and coarse-grained, and contracts in bulk. This dehydration, like that produced by freezing or other means, appears to be irreversible.

The final increase in the volume of sediment must be attributed to a cause similar to that producing the first increase, namely, the combination of the solute with the kaolin; but in this case it will be with the partially dehydrated kaolin, and the solute will be present as hydrates of very different constitution from those in dilute solutions. The slight turbidity of these liquids is due to their increased viscidity.

Alkalies produce flocculation, as well as acids and salts, but not till the proportions present are 100 to 1,000 times greater.

In the case of alkalies, the decrease in the amount of matter in suspension is preceded by an increase; but this cannot be due to a reversal of flocculation, for there is no corresponding depression in the sediment-volumes. It is explained by the fact that combination with alkalies requires the presence of these in excess.

A true reversal of flocculation would be produced by alkalies in the case of clay flocculated by carbonic acid, as when a clay soil is dressed with lime.

MELTING POINT OF COAL ASH.—E. J. Constam (*Zeits. Ver. Gas- und Wasser-fachmänner in Oesterr. Ung.*, Oct. 15th, 1913). The melting point of ash was determined by heating—in an electric furnace, in a tube closed at one end—equilateral pyramids obtained by moulding from a paste and afterwards drying. The tube has the properties of an absolutely black body, so the decrepitation, intumescing, and melting of the pyramids of ash can be observed optically, as well as the fusion temperature. It was inferred (1) that the melting point of the ash is not affected by the percentage of ash in a coal, (2) the melting point of the ash is a characteristic of the coal seam, and (3) the melting point of coal ash is not affected as a rule by coking or the temperature of coking. The author classifies coal ash—the melting points of which were found to range from 1,150° to 1,700° C.—into groups: (1) readily fusible—below 1,200° C.; (2) fusible—1,200° to 1,350° C.; (3) difficultly fusible—1,350° to 1,500° C.; (4) very difficultly fusible—1,500° to 1,650° C.; and (5) refractory—above 1,650° C. In the samples investigated, chemical analysis indicates that lime, iron, and sulphur (pyrites) lower the melting point, while alumina raises it. The fusibility of an ash can be reduced by adding alumina or clay, or by mixing the coal with another have a difficulty fusible ash. Slate is generally refractory, but it becomes the core of large lumps of clinker which interfere with the working of the furnaces.

The limits mentioned for the melting point of coal ash are: coke for central heating plant, above 1,300° C., anthracite for central heating plant, above 1,400° C., boiler coal, above 1,400° C., locomotive and producer coal, above 1,500° C., or fluxing at about 1,200° C. Gas coal should have ash with a fusing point not below 1,300° C., and should have as little as possible pyrites and slate. The author believes the determination of the melting point of the ash will acquire increased importance in the valuation of coals, especially gas coals.

THE CRUCIBLE SITUATION IN AMERICA.—M. McNaughton (*Metal Industry*, 11, 506, 1917). Before the war all the clay and probably 95 per cent. of the plumbago used for crucible purposes were imported, the clay coming from Klinkenberg in Western Germany. The remarkable quality, uniformity, and adequate supply made this clay the best known for crucible making. The makers usually kept a year's supply on hand so as to allow of natural drying (the clay containing about 22 per cent. of free water), and also to facilitate detection and correction of slight variations in quality. Soon after the war started the supply of Klinkenberg clay was cut off, and crucible manufacturers had to seek a substitute. Previous to the war 25 to 30 average heats were secured with average sized crucibles used in standard rolling mill practice. In early trials with substituted clays some were utter failures, and in certain cases 4 or 5 heats were secured. At the present time (Dec., 1917) the range

of average service is 15 to 20 or 25 heats. The cost of the clay is more than double what the German clay formerly cost. A blend of different clays is found to give the best results.

The plumbago for crucible making comes mostly from Ceylon, not more than 10 per cent. being supplied from Madagascar and America. The Ceylon plumbago is more cubical than the Madagascar and American graphite, which is in the form of thin flat flakes. The price of Ceylon plumbago has risen to more than three times the pre-war price.

Both materials—clay and plumbago—are being supplied much more satisfactorily, and makers expect to be able to meet any emergency that may arise.

GRAIN SIZE.—G. H. Gulliver (*Metal Industry*, 12, 228, 1918). The term "grain size" is usually applied to the average area of section of a crystal grain, found by dividing the number of sections visible to a given micrographic area into the magnitude of the area; and the use of the term is often considered justified if the examination of several micrographs, taken at different positions and directions in the piece, yield nearly the same numerical value of the mean granular area. A cursory examination of a micrograph shows that there is a large variation in the size of the grain sections—too large, in fact, for the satisfactory employment of a mean if the sections were disconnected quantities. Actually, the areas of the various grain sections do not vary independently; the real significance of "grain size" is mean granular volume, and the term implies that the volume of each crystal grain approximates with sufficient nearness to the average volume to allow the term to have a double meaning.

The size of a grain is measured as a two-dimensional quantity, because the determination of a granular area is much easier than that of a granular volume, and, for the same amount of trouble, it gives a more reliable indication of size than a linear measurement would do. If all the grains in a mass are of nearly the same size and shape, it does not much matter (apart from the question of convenience) whether the size is measured as a one, two or three-dimensional quantity, since the three quantities bear nearly fixed relations each to the others; but variation in the size of the grains, in shape, or in manner of distribution, disturbs those dimensional relations.

Attention is confined here to the relation between the mean volume of a grain and its mean area of section, when the material shows only one kind of structural constituent. If the grains are distributed in random manner throughout the mass, their polygonal sections on the prepared surface are of variable magnitude. But with grains of approximately equal volume, and approximately the same compact shape, a micrograph of given area, large compared with the maximum area of section of a grain, shows a nearly constant number of grain sections, from whatever part of the mass it is obtained. In the last sentence "approximately equal volume" may be interpreted as indicating a permissible variation in volume of, say $\pm$ 10 per cent.; "approximately the same compact shape" may be regarded as meaning a polyhedron of, say, $12 \pm \frac{4}{2}$ faces, with a permissible variation of $\pm$ 5 per cent. among its corresponding diameters; and "large" may be taken to mean that the measured area of the micrograph includes not less than 200 grain sections. Before the manner of distribution can be determined, it is necessary to discover a few specimens in which the grains are of reasonably uniform size; so far, no such specimens have been found, and the effect of distribution must be left out of account.

To determine the approximate relation of the two-dimensional grain-size to the mean granular volume, suppose the mass of material to be a cylinder of any form of section, of height H and cross-sectional area A. Let N be the total number of grains in the cylinder. If d be the mean diameter of a particular grain, the volume of that grain is kd^3, where k is a numerical fraction which depends upon the shape of the grain. Let d be the average value of d for the N grains. Then if the variation among the grains is limited as stated above, the average granular volume is equal to $k(d)^3$, with an error of not more than ± 4 per cent.

Let parallel slices of the cylinder be taken at small distances h apart, and let n be the mean number of grains cut by one face of each slice. Then the total number of grain sections made by one face of all the slices is:

$$nx\,(\text{number of slices}) = n\,\frac{H}{h}$$

The total number of grain sections is also:

$$Nx\,(\text{number of sections of each grain}) = N.\frac{d}{n}$$

$$\text{Therefore } n.\frac{H}{h} = N.\frac{d}{h} \text{ and } n = N.\frac{d}{H} = \frac{AH}{k(d)^3} \div \frac{d}{H} = \frac{A}{k(d)^2}$$

Or the mean area of a grain section, within the limits of error already stated, is $\frac{A}{n} = k(d)^2$

The diameter which is to be regarded as the mean diameter d of a grain is that which will yield an average number of sections of the grain; it may be taken as the arithmetic mean of the diameters of two spheres approximating as closely as the shape of the polyhedron will allow to an inscribed and a circumscribed sphere.

The value k for a polyhedron of compact form, having an average of 12 faces, is somewhat less than $\frac{1}{2}$, say $0{\cdot}48 \pm 5$ per cent. Thus the approximate area of a grain section is $\frac{A}{n} = \frac{(d)^2}{2}$

And the mean volume of a grain is, in round figures, $k(d)^3 = \frac{3}{2}(n)^{\frac{3}{2}}$ where $\frac{A}{n}$ is the area usually denoted grain size.

From the above result may be obtained another which promises to be of greater interest, though the degree of numerical accuracy is less than before. As previously stated, if the grains are approximately equal and equiaxed, a section of the mass taken at random yields a nearly constant grain size. But the converse is not necessarily true, and a constant two-dimensional grain size might only indicate a recurrent form of distribution, as for instance one in which a large grain is surrounded by several smaller grains. A ready means of detecting a gross departure from uniformity is to measure the areas of the grains on a suitable micrograph, and compare the maximum with the mean.

The area of the largest section which can be cut from a grain is cd^2, where c is a numerical fraction approximating to $0{\cdot}8$ when the section is a polygon of compact shape with 6 to 10 sides, and d has the meaning already assigned to it. Taking the limits of variation in the grains as before, and ignoring for the moment any variation in the coefficient c, the extreme limits of variation of the maximum area are about ± 12 per cent.

The value of the ratio of maximum to mean grain area, as actually measured, will vary on account of (1) Variation in the size of the grains. (2) Variation in the shape of the grains. (3) Improbability of any one grain being cut exactly along a plane of maximum area. The ratio will be increased on account of (1), and decreased on account of (3). As regards (2), the value of c changes, but not greatly, with the number of sides of the polygon. The maximum variation of the ratio is about 20 per cent., and the value of the ratio is:

$$\frac{\text{maximum grain area}}{\text{mean grain area}} = \frac{0{\cdot}8}{0{\cdot}48} = 1{\cdot}7 \pm 20 \text{ per cent.}$$

or, roughly, from $1\frac{1}{2}$ to 2. An alteration of the arbitrarily chosen limits of variation among the grains will alter the limits of accuracy of the numerical result.

The above ratio, though its possible values lie between somewhat wide limits, may be usefully employed as a *criterion of uniformity* of the grains; that is to say, if in a section of a metal, with approximately equiaxed grains, the ratio of the largest grain area to the mean grain area is sensibly greater than 2, the grains cannot be described as of nearly uniform size. Geometrical distributions of grains are possible from which special sections would give a value of the criterion lying anywhere between 1 and 2, or even considerably above 2, but such distributions are not regarded here. A criterion less than about $1\frac{1}{2}$ would indicate a special kind of distribution.

The value of the ratio of maximum to mean grain area in some specimens measured—characterised as neither numerous nor entirely suitable, though no details are given—was found to lie between 3½ and 5, the higher values being obtained for longer periods of annealing; the grain size was thus far from uniform, and annealing increased the deviation from uniformity.

With slight modification the above arguments may be extended to certain alloys which show more than one structural constituent. Where the crystal grains, though nearly uniform in shape and volume, are not of compact form, the use of the term "grain size" is not convenient without proper reference to the shape of the grains; examples are the elongated prisms of a drawn bar and the pyramids of a chilled casting.

REFRACTORIES IN THE IRON AND STEEL INDUSTRY.—H. W. Croft. A paper read before the *American Iron and Steel Institute*, Chicago, 1913, by the President of the Harbison-Walker Refractories Co., dealing with the classes of materials for lining metallurgical and other furnaces. The word refractories is employed as meaning materials used to resist the action of heat, slags and gas continuously at work upon the lining of practically every furnace engaged in metallurgical operations. Refractories fall into three classes—fireclay bricks, silica bricks, and basic bricks (magnesite and chrome bricks). The official records of the U.S. Government show that in 1912 the quantity manufactured was of fireclay bricks 778 millions, silica bricks 136 millions, and basic bricks 14 millions, or 83·8, 14·7, and 1·5 per cent. respectively of total.

Coal measure clays are divided into three classes: the flint vein, lying within the Pottsville conglomerate series, and all the other clays occurring higher in the coal measures, known as upper vein clays. The latter may be considered as solely plastic clay. So far the known deposits of the flint clay of this formation are restricted to limited areas in Pennsylvania, Maryland, Ohio, and Kentucky. Of the clays in other measures, scattered bodies of flint clay occur in Missouri, but differ from those in Pennsylvania. They occur in pockets or sink holes of limestone formations. Most of the high grade fire-bricks required in the iron and steel industry are made of the coal measure flint and plastic clays. Various mixtures are used, ranging from about 90 per cent. flint clay and 10 per cent. plastic clay in the most refractory bricks to 100 per cent. plastic clay for the least refractory bricks.

Manufacture of fireclay bricks.—The selected clays are broken into small lumps, mixed in suitable proportions, and ground in the wet pan. The mass is then moulded into shape, tempered on a hot floor, repressed, thoroughly dried, and burned at 2,600° to 2,650° F. (about 1,427° to 1,454° C.) Bricks produced by this old hand-made process are open, porous, and resistant to sudden changes of temperature. Various machines have been introduced, but as regards high grade bricks the most noticeable development in the machine-made product is in the manufacture of blast furnace bricks on a steam or other powerful press. The machine-made bricks are denser by 7 to 8 per cent. than hand-made bricks. Most cheaper grades of bricks are made by machinery.

Uses of fireclay bricks.—In the blast furnace lining three kinds of bricks are used; for the hearth and bosh, bricks of maximum refractoriness and capable of resisting the action of fused or semi-fused furnace contents; for the inwall, bricks to stand high temperatures and abrasion; and for the top, dense and tough bricks to withstand wear and resist the action of gases. The water-cooled furnace, with 12 inches or less of lining, needs the very highest grade of refractories in the form of bricks of more uniform dimensions and of much greater density than formerly. This result was secured by using a mixture of clays giving minimum shrinkage and by manipulation designed to increase their bond to the maximum. The material was finally made into 12-inch blocks on a steam press, and the result was a lining which fulfilled all expectations. After 8 months run, the furnaces in which the lining was put was blown out to make some slight changes in the shell, and the lining was found to have a thin lining of carbon which, when chipped off, exposed the face of the brick in many cases with the original skin intact. An examination showed that no spalling occurred. The lining also resisted the abrasion of

the stock and channelling blast, and was practically impermeable to gases. A number of similar linings have since been installed.

To produce bricks with minimum impurities (and therefore higher refractoriness) without loss of bond needed special treatment in almost every department of the manufacture, and of course involved considerable increase in cost as compared with standard furnace bricks. Several hand-made linings were produced in this manner. On similar lines, but with less hand-picking, rehandling and washing of clays, other hand-made linings were produced at less cost. Hand-made and machine-made linings are in about equal demand. In furnace tops the machine-made brick should apparently be superior. The possibility of making bricks of more regular and uniform dimensions than the hand-made process should also insure better bricklaying.

In *hot-blast stoves* firebricks act merely as a thermal reservoir, but are subject to widely varying temperatures, to enormous loads, and often to the fluxing action of the flue dust in unwashed gases. As in blast furnaces, here also there is a development in the use of bricks of greater density and higher refractoriness, with a decided tendency to substitute a higher for a lower grade brick. Another recent development is the use of silica bricks in the flash walls and domes, which materially increases the life of the stoves. Although in blast furnaces and stove piping and connections high temperatures are not involved, the bricks need toughness as well as mere density, and recently a high grade brick specially designed for this has proved economical.

The *chequer bricks* used in *open hearth furnaces* and *soaking pits* are subject to the same considerations as stove bricks, and here again the tendency is unquestionably towards using higher grade bricks.

In many heating and welding furnaces the bricks are subjected to very high temperatures and often to sudden variations. Owing to the limited refractoriness of the clays available, substantial betterment of results must arise from improved furnace design or the use of silica instead of clay bricks.

In *boiler settings* for the side walls many are finding a blast furnace brick economical, and even expensive bauxite bricks are sometimes used because of their greater resistance to clinkering.

Even in the case of gas producers, certain manufacturers have entirely discontinued the use of other than the highest grade of bricks, and are experimenting with bauxite bricks and other linings.

Silica bricks in Pennsylvania are made from a quartzite in the Medina and Oneida sandstone formation, good rock occurring only in limited areas, such as the Mt. Union and Hollidaysburg districts. The Baraboo quartzite of Wisconsin, from which bricks are made in the Chicago district, belongs to an older formation and is also found in limited areas. The rock from which silica bricks are made in Alabama has not yet been distinctly located geologically. The Alabama and Pennsylvania rocks are greyish, whereas the Wisconsin rock appears reddish, but their analyses show only slight differences.

The rock is broken at the quarry, and crushed in small pieces at the works and ground to the proper fineness in the wet pan, 2 per cent. of lime usually being added for bond. The bricks are made much in the same way as clay bricks, but are burned at a higher temperature.

Owing to the high refractoriness, slight expansion under heat, and exceptional conductivity of silica bricks, their use in the manufacture of iron and steel has increased enormously.

In *open hearth furnaces*, whether basic or acid, the use of silica bricks is no longer restricted to the side walls, blocks, and roof, but is extending to the chequers, roofs and walls of the regenerators. A few years ago an average of 250 to 275 heats was considered a fairly good life for the open hearth roof. Now an average of 400 to 500 heats is not uncommon, and single runs of 800 to 900 heats are frequent. This change is mostly due to improved furnace design, methods of operation, and better bricklaying, but the silica bricks are also better.

In the *by-product coke oven* silica bricks have in recent years displaced clay and quartzite bricks completely above the oven floor and in certain portions beneath. It has developed surprising qualities in withstanding unavoidable

changes in temperature and in meeting actual operating conditions. This use of silica bricks is wholly an American development. A few years ago 24-hour coke was normal, now, by the use of silica, with its greater refractoriness and conductivity, it is possible to make 15-hour coke.

In Eastern *crucible practice* silica has to-day displaced clay bricks in fully 90 per cent. of the tonnage.

One of the newer uses is in *heating furnaces*. Silica has in gas-fired pipe welding furnaces proved a great economy and is adapted wherever there are no sudden changes of temperature. In the roof of large span and small rise the absence of shrinkage gives silica an advantage.

In the boiler arch there are too rapid variations of temperature to render its use satisfactory, but where boilers are gas-fired and sudden changes of temperature are prevented, the value of silica bricks has been demonstrated.

Magnesium oxide, commonly called *magnesite*, is best adapted as a refractory material for lining the bottoms and sides of furnaces to resist the action of basic slag. Magnesite occurs naturally as a white or amorphous variety, and a crystalline form. The difficulty of thoroughly calcining this white amorphous magnesite makes its use as a refractory impracticable. The crystalline form is found in Austria, Hungary, and Sweden. The crude magnesite is burned in shaft or rotary kilns, crushed, sorted and sacked, ready for furnace bottoms, or to be made into bricks. The composition of the prepared material is approximately 82 to 88 per cent. magnesia, 3 to 4 per cent. lime, 3 to 5 per cent. silica and 5 to 7 per cent. ferric oxide. A magnesite of this composition will flux sufficiently in a furnace to make a hard vitreous bottom, or if burned into bricks will have a strong bond.

The process of manufacturing magnesite bricks differs little from that employed in making other bricks, but the temperature of burning is very high, near 3,000° F. (about 1,650° C.) Most of the magnesite and magnesite bricks used in the iron and steel industry is for the bottoms of basic open hearth furnaces and in the side-walls extending above the slag line. It is also widely used in the ports and blocks, and the end walls and uptakes are built of it in many furnaces. The bottoms and side-walls of certain electric furnaces are also of magnesite.

Chrome ore or *chromite*, is highly refractory and resistant to both acid and basic slags. In practice a chrome ore running from 40 to 50 per cent. chromic oxide and from 3 to 7 or 8 per cent. silica makes the best refractory. Chromite bricks are used in open hearth furnaces, soaking pits and dolomite kilns. It is also ground and used as a patching and daubing mixture for repairing jambs, side-walls, ports and blocks of open hearth furnaces. The process of making chrome bricks is practically the same as in making magnesite bricks.

Conclusions.—There is a tendency for gradually substituting the higher grade refractories for the lower, magnesia and chrome bricks frequently displace high grade fireclay bricks to resist basic slags, and silica bricks displace clay bricks where the maximum refractoriness is required and where the temperature variations permit. The number and variety of difficult shapes is fast increasing. Brickwork is laid with greater accuracy, and less than half the clay or cement formerly used for laying is employed.

In the past 25 years no new beds of fireclay of a quality better than formerly used have been discovered. The brickmaker has therefore to meet new conditions confined to a mixture of known clays in various proportions, with suitable additions of calcined clay; to grinds of various degrees of fineness; to burns of varying degrees of hardness; and to special treatment of the clays. After a careful hand selection, any effort to increase the refractoriness by a further elimination of even a small percentage of impurities involves much rehandling in their weathering and washing, which is costly.

In a discussion of Mr. Croft's paper, Mr. A. N. Diehl (superintendent of blast furnaces, Carnegie Steel Co., Duquesne, Pa.) pointed out that the ideal refractory material should (1) prevent heat losses through radiation, (2) withstand the heat without altering its chemical or physical relations, (3) have sufficient hardness to prevent abrasion and yet not spall, (4) have a low factor of expansion and contraction, and (5) be inert to chemical reactions taking

place within its confines. No material is known which will fill perfectly all these specifications. Hence the selection of different proportions of clays for the various demands in blast furnace requirements, and the combination of silica roof and basic bottom with a neutral zone in open hearth practice, etc. The refractories encountered are principally oxides, either alone or in combinations, and are principally of a high fusing point.

In the *blast furnace*, with its reducing atmosphere, abrasive material, corrosive slagging reactions and high temperatures, the material best suited according to present knowledge is found to be a brick made of clay, or a mixture of clays having different properties so proportioned as to suit the conditions imposed in the different parts of the furnace. At the *top* the bricks are generally a mixture of flint and plastic clay, the latter greatly predominating to give hardness and ability to withstand the continuous abrasion of the stock sliding off the bell. In modern practice numerous devices have been suggested and tried for the protection of the lining at this point in the furnace. Cast-iron wearing rings of varied design have given the best results, so that the difficulties here have been largely overcome. The *hearth and bosh* brick is a mixture of flint clay with only sufficient plastic clay to give it a bond. The proportion is such as to withstand the intense hearth and bosh temperatures and slagging actions. Bronze cooling plates and water-cooled boshes have aided greatly in keeping the bricks below their fusion and fluxing point, thereby protecting these portions, with the result that a hearth and bosh will generally last a million-ton campaign. The so-called *inwall*, situated between the top and hearth and bosh, is often left to the mercy of the stack reactions, and in modern practice it is in this part of the furnace that the most violently destructive chemical reactions take place. The temperature ranges from 1,200 to 2,500° F. (about 650° to 1,370° C.), so the bricks should be both hard and refractory. A compromise mixture of clays between the top and hearth and bosh proportion is used. It is at this point that further investigation should be concentrated, as 90 per cent. of the blast furnaces are blown out because of failure at this point. In almost every furnace lining 30 to 35 feet from the top the lining starts to cut back at an angle of 12 to 14 degrees with the vertical towards the shell and again starts to slope from the shell at an angle of 18 or 20 degrees, approximately the original thickness at the bosh. The brickwork generally for about 10 feet above the mantle is very little affected. It is in the inwall portion that the temperature is high enough to effect the limestone calcination and free the lime with all its avidity for combination. Any localization of high heat at a point where calcined lime or alkalies are in contact with the bricks may bring an incipient fusion or softening and greatly assist in the failure thereat. A case of irregular filling or unequal driving may cause the coarse material to deflect to one side and allow the easy passage of hot gases through the consequent course of least resistance and further this local heating. Varied slag constitution, light burdens and high air volumes are conducive to hot tops and high melting furnaces, and therefore consequent stack temperatures high enough to cause a fluxing action in the inwall portion. In almost every case of blowing out, when material is found clinging to the sides of the stack, free lime is greatly in evidence; also as much as 40 per cent. of sodium and potassium oxides have been found in many cases and the brick surfaces are often vitrified. Abrasion is the other great factor, and abrasive action is more pronounced when the bricks are softened by fusion action. That the inwall becomes thicker again above the mantle on the average cut out lines is further evidence that the lime has become partly satisfied with the materials in the charge and is not so eager to attack the brickwork. The combination of heat, fluxing, and abrasion is most destructive about 20 to 25 feet above the mantle, and this point may be termed the point of maximum erosion.

The most successful installations of cooling plates have been where the plates (cast-iron L plates, or bronze plates) have been placed 18 to 24 inches from the face, thereby allowing the furnace a certain latitude in forming its own lines. The thin lined water-cooled furnace performs the same cooling functions, *i.e.*, keeps the bricks cool enough to retard chemical action and

enable them to retain most of their original hardness to withstand abrasive and chemical action. In this way a 13-inch thickness of brick wall has stood in some thin lined furnaces for considerable periods without being affected. Most thin lined furnaces fail very rapidly if a small defective spot be formed, chiefly because the wall has little stability in itself, and therefore the bricks fall in slowly until a serious lining condition arises. Angle iron projections have been used to hold the brick in sections, which is a step in the right direction. In some recent furnaces using outside cooling the wall is made thick enough to withstand a small local failure without disturbing the bricks above it. It would seem that either a chemically inert material of hard and refractory nature with little heat-expanding properties, or a further development of a proper water-cooling system should put the durability of the inwall on a par with the top and bosh.

For *stove* practice the bricks should withstand pressure and be so ground as to absorb and release heat rapidly without spalling. The bricks on the top of the chequer work should be refractory, hard burned and capable of withstanding high temperatures. They should be so burned that no further shrinkage can take place in the stove, otherwise twisting and warping may result.

In testing first quality 9-inch straight fireclay bricks, some hand pressed and some steam pressed, it was found that for the former the average specific gravity for 5 samples was 2·01, and for the latter 2·13. In testing 8 of the 10 bricks for spalling when chilled from high temperatures, none showed any signs of chipping either when air-cooled, when suddenly immersed in water, or when sprayed. As regards absorption of water, one of each kind took up 4·12 per cent. of its volume, or 6·02 per cent. by weight for the hand pressed, and 5·76 per cent. for steam pressed. Thus the steam pressed brick appears to have a density 6 per cent. greater than the hand pressed brick, and is just as capable of withstanding sudden changes in temperature. The average weight per cubic inch of steam pressed brick was found to be 1·24 oz., and of hand pressed brick 1·17 oz. Experience has shown that in handling bricks in sheds and rehandling for use the breakage loss is 50 per cent. less in the steam pressed than in the hand pressed bricks. This is also true regarding breakage in transit. For some purposes (as irregular shapes) hand made bricks will always be preferable. The smaller cost of laying machine made bricks, owing to more perfect shape and less breakage in handling, is a great factor.

Refractory material is in most cases considered a renewal, and there is very little scrap value. The average open hearth furnace will last 5 to 6 months, and a blast furnace lining about 4 years. Of the cost of materials for open hearth renewals for 6 months (about £30,000), 78·30 per cent was for refractories, and of the cost of material used in 6 consecutive blast furnace linings (about £35,000) 66·08 per cent. was for refractories. There is also the loss due to gradual inefficiency as the brickwork erodes and the decreased tonnage per unit during the times of renewal.

REFRACTORY LININGS AND MATERIALS.—J. W. Haulman (*Blast Furnace and Steel Plant*, 5, 159, 1917). The first part of refractory work in a steel department begins with the lining of ladles used in transporting the molten metal from the blast furnaces to a metal mixer, and from there to the Bessemer converters or to open hearth furnaces. This lining is about the least affected of any, owing to the fact that the metal is colder now than after it has undergone a transformation, and there are no reactions taking place in this ladle. A practical lining for such ladles that has given excellent results is a single fire-brick lining against the ironwork or "shell" of the ladle, and on top of this flat course of brick is rammed a mud cake lining which can be easily and cheaply prepared. "The formula for a mud cake lining calls for six parts of crushed fireclay brick bats, two parts of a clay that may be found in almost any locality, and ten shovels of a silica stone, ground together in a mixing pan, with enough water added to make it plastic." The clay should be as low as possible in fluxing impurities—a tough plastic ciay, usually found in the low-lands and swamps, and should contain 54 per cent. silica, 30 to 32 per cent.

alumina, 10 to 12 per cent. combined water, with not more than 3 to 4 per cent. ferric oxide. As the blast furnace iron runs into the ladle at about 2,860° F. (about 1,570° C.) the lining must be refractory enough to withstand this temperature easily. After preparing the mixture in a grinding pan it is thrown on a board and rammed into a solid mass, and then cut into cakes of convenient size, placed in the ladle next to the brickwork, and rammed down to a smooth solid surface, and dried very thoroughly before being used.

Such a lining will last in an iron ladle about 48 hours' constant use, or until it is so badly skulled that it is unfit for use, after which the ladle is cooled and the "skull" is easily removed by cutting around the edges; when the ladle is turned upside down the "skull" will drop out, taking the inexpensive mud cake lining with it, without any injury to th ebrickwork underneath, which serves its insulating purposes without loss.

Fireclay, when finely ground and mixed with water to a paste, forms an excellent mortar used in connection with the laying of fireclay brickwork. The bricks are dipped in the mortar and rubbed together making a brick to brick joint, the clay being equal in refractoriness to the brick itself. It is also used in mixtures with the more plastic clay to good advantage, where a combination of plasticity and refractoriness is desirable.

A good firebrick should contain approximately 50 to 55 per cent. silica, 35 to 40 per cent. alumina, 2 to 5 per cent. ferric oxide, not more than ½ per cent of magnesia, and only a trace of lime.

Some sandstones are used in the manufacture of silica bricks, or are cut into sizes and shapes for certain linings at a very low cost and used in the place of costly silica bricks. Such stone should be well seasoned and thoroughly dried before being used as a lining material. This sandstone or silica rock is very commonly used for the lining of Bessemer acid converters. The stone is dressed into such shapes that will turn a circle of the proper diameter. The analysis of this stone will show about 94 to 96 per cent. silica, 3 to 4 per cent. alumina, and traces of ferric oxide and magnesia.

The lining is started at the nose of the converter, the converter being set in a vertical position with the nose down. The stones are keyed in from the starting point until the entire circular wall is built up. The stones are laid in a mortar made from the spalls of the same stone finely ground and a small amount of good clay added to make it plastic. The joints in the masonry should be made as close as possible, otherwise the molten metal will find its way into the joints and cause rapid destruction of the lining. Silica bricks have been used as well as clay bricks in the lining of acid Bessemer converters, but to no better advantage than the silica rock lining and at a greatly increased cost.

In putting up a bottom section for a converter a 9 inch to 20 inch circular lining is put around the shell of the section or extended out to a circular plate through which the tuyeres are placed. The tuyeres are placed up through this plate and keyed. A layer of ganister is rammed on the plate around the tuyeres, and on this are arranged large tile bricks long enough to reach to the level of the tops of the tuyeres; usually they are placed between the tuyeres, their width being the same as the diameter of the tuyere, but sufficient space must be left between the tile and tuyere to allow the ganister to be rammed firmly, the tile acting as a binding agent for the ganister and as a support to the tuyeres. The ganister is rammed in thin layers one upon the other, until the level of the tops of the tuyeres is reached. The bottom is then put in a drying oven, and baked at a moderate heat for 3 or 4 days, after which it is ready to be attached to the converter.

"The ganister used in the preparation of converter bottoms should be dry ground, and is composed of a mixture of good quality clay brick bats, fireclay and swamp clay with a little coke dust." When thoroughly ground and mixed it is put up in a bin with enough water added to make the moisture about 10 per cent. when ready for use. The mixtures used should give a composition of about 50 to 60 per cent. silica, 25 to 35 alumina, 1 to 3 per cent. ferric oxide and magnesia, and 10 per cent. moisture.

Cupolas are lined generally with a 4½ inch firebrick lining against the shell, and next to this is placed another brick lining of specially designed

blocks 10 to 14 inches long, making a total wall thickness of 14½ to 18½ inches. On the first run of a cupola, much of this block lining will be eaten away, and it is then patched up with a silica rock similar to the stone used in the lining of converters.

For ladles used for handling of the metal from converters or open hearth furnaces, scarcely any substitute can be offered for bricks, but a low grade fire-brick will usually answer the same purpose as a more expensive one, and the bricks can be protected to a great extent by putting in mud bottoms and also extending a mud lining up along the breast of the ladle where the flow of metal from a furnace first strikes.

VALUATION OF LIME FOR VARIOUS PURPOSES.—R. K. Meade (*J. Ind. Eng. Chem.*, 10, 214, 1918). Generally speaking, the building trade is most interested in colour, plasticity, and possibly strength; while the chemical manufacturer wishes purity from carbon dioxide, silica, and the oxides of iron and alumina, and to have either a high or low content of magnesia as the process may require.

There are no standards of physical properties and the builder grades his lime largely by means of experience. No colour scheme or standard grade of colour has been devised, nor are there any methods generally accepted as reliable for testing plasticity. At the larger chemical works quite reliable methods are employed for the valuation of the lime used. At many of the smaller works very crude methods of analysis are employed. The purpose of this paper is to outline the methods most generally employed for the chemical analysis of lime.

Classification of Lime.—The standard specifications of the American Society for Testing Materials (1915) recognise two grades:

(*a*) *Selected*—well burned, picked free from ashes, core, clinker, etc.

(*b*) *Run-of-kiln*—well burned, without selection.

Quicklime is either (*a*) *lump lime*—kiln size, or (*b*) *pulverized lime*—to pass ¼-in. screen.

Quicklimes, according to chemical composition, fall into four types: (*a*) High calcium. (*b*) Calcium. (*c*) Magnesium. (*d*) High magnesium.

The chemical limits prescribed in the specifications are:

	High Calcium		Calcium	
	Selected per cent.	Run of Kiln per cent.	Selected per cent.	Run of Kiln per cent.
Calcium oxide	90 (min.)	90 (min.)	85-90	85-90
Magnesium oxide				
Calcium oxide + Magnesium oxide ..	90	85	90	85
Carbon dioxide (max.)	3	5	3	5
Silica + Alumina + Oxide of iron (max.)	5	7·5	5	7·5

	Magnesian		High Magnesian	
	Selected per cent.	Run of Kiln per cent.	Selected per cent.	Run of Kiln per cent.
Calcium oxide				
Magnesium oxide..	10-25	10-25	25 (min.)	25 (min.)
Calcium oxide + Magnesium oxide ..	90	85	90	85
Carbon dioxide (max.)	3	5	3	5
Silica + Alumina + Oxide of iron (max.) ..	5	7·5	5	7·5

Hydrated lime takes the same chemical classification as the lime from which it was made.

Uses of Lime.—In the building trade lime is used: (1) Mixed with sand as a bonding material in laying brick and stone; (2) for plastering; and (3) hydrated and mixed with Portland cement to confer certain properties (such as plasticity and impermeability to water) on mortars of the latter.

For bonding brick and stone, the important qualities of lime are sand-carrying capacity, crushing strength and tensile strength. For plastering, selected lump lime or hydrated lime is employed, good colour and plasticity and thorough hydration being important. The lime must not "pit" or "pop"

and must not give too great change of volume during setting; the quicker the setting the better. Magnesian or dolomitic limes are generally considered preferable to calcium limes for plastering.

For use with Portland cement, very impure and off-colour hydrate may be successfully employed, the fineness and completion of hydration being most important.

The tests usually employed for building limes are for chemical composition, sand-carrying capacity, crushing strength, tensile strength, and setting time, and in the case of hydrated limes also tests for fineness and constancy of volume.

Large quantities of quicklime and hydrated lime are used in agriculture, authorities differing as to whether magnesium and dolomitic limes are as efficient as calcium lime. The cheapest grades of lime are generally used for fertilizer, its value depending entirely on the cost per unit of calcium oxide (or calcium and magnesium oxide if the latter is considered equivalent to the former). For convenience in applying, ground lime is preferable to lump lime, while hydrated lime (being absolutely fine) is preferable to either.

Many sprays used for trees and plants are prepared from lime, the value of which for this purpose depends entirely on the percentage of free calcium oxide which it contains. Magnesia is of no value here.

In the manufacturing arts, a very pure lime is always wanted, and its value depends entirely on the percentage of uncombined calcium oxide (sometimes calcium and magnesium oxides combined). In the manufacture of caustic soda and of sugar, magnesia is considered harmful.

Soda ash produced by the "Solvay" or ammonia process requires a high-calcium lime, which is also needed for producing *caustic soda* from soda ash, and in the preparation of *ammonia*, of *potassium dichromate*, and of *paper and pulp* by the soda process. In making *calcium carbide* magnesia and impurities in the lime are decidedly objectionable, and for *bleaching powder* magnesia in the lime should be as low as possible. For *calcium cyanide* pure high-calcium lime is desired. For *calcium acetate* (*acetate of lime*) magnesia and impurities are not harmful in themselves, but as in all the foregoing cases the value of the lime depends solely on the percentage of free calcium oxide. The same is true as regards *glycerine*, *lubricating greases and fat industries*, of the *purification of illuminating gas*, and the *purification and softening of water*. For *sugar* pure high-calcium lime is required, magnesia and silica causing trouble in the process, and for tanning *leather* iron oxide is objectionable because of its staining action. For *sand-lime bricks* a pure high-calcium is desired, though impurities are not objectionable of themselves; magnesia should not be very high, and if hydrate is used it must be completely hydrated. For *paper and pulp by the sulphite process* a high-magnesium or dolomitic lime is required, impurities being objectionable only as taking the place of the free oxides of calcium and magnesium. For *magnesia* dolomitic limes only are required, and the value depends solely on the percentage of free magnesium oxide. For *glass* both high-calcium and high-magnesium limes are used; the oxide of iron should be low, but other impurities are immaterial. For *cold water paints* hydrated lime is used, and fineness and colour are the main points, chemical composition being unimportant. In *metallurgy* both high-calcium and high-magnesium limes are employed, impurities being objectionable only when in large quantity; generally the lime should be burned much harder than usual.

Physical Tests.—The only practical tests of lime for which standard methods are available are those for determining (1) the proper or normal consistency of lime paste, for which purpose the Chapman apparatus is now pretty generally employed, (2) the percentage of waste in quicklime, and (3) the fineness and constancy of volume of hydrated lime. These latter tests are included in the standard specifications of the American Society for Testing Materials, which also give instructions as to sampling.

For *percentage of waste in quicklime*, an average 5-lb. sample shall be put into a box and slaked with water to produce the maximum quantity of lime putty, care being taken to avoid "burning" or "drowning" the lime. After standing 24 hours it should be washed (not rubbed) through a 20-mesh

sieve by a stream of water having a moderate pressure. Not over 3 per cent. of the weight of selected quicklime nor 5 per cent. of run-of-kiln quicklime should be retained on the sieve. The sample of lump lime taken from this test shall be broken to all pass a 1-in. screen and be retained on a $\frac{1}{4}$-in. screen. Pulverized lime shall be tested as received.

For *fineness of hydrated lime*, 100 g. shall leave not over 5 per cent. on a standard 100-mesh sieve, and not over 0·5 per cent. on a standard 30-mesh sieve.

For *constancy of volume*, equal parts of hydrated lime and volume-constant Portland cement shall be thoroughly mixed together and gauged with water to a paste. Only sufficient water shall be used to make the mixture workable. From this paste a pat about 3 in. in diameter and $\frac{1}{2}$ in. thick at the centre, tapering to a thin edge, shall be made on a clean glass plate about 4 in. square. This pat shall be allowed to harden 24 hours in moist air, and shall be without popping, checking, cracking, warping or disintegration after 5 hours' exposure to steam above boiling water in a loosely closed vessel.

The methods employed for the other physical tests for lime are in general quite similar to those used in testing cement, though details are apt to differ with each operator. The first step is always to determine the proportions of lime and water which are necessary to make a paste of standard consistency, which is now usually done by means of the Chapman apparatus (see *Amer. Soc. for Testing Materials*, 13, 1,045, 1913).

For determining the *crushing and tensile strength*, a mortar consisting of standard lime paste (equivalent to one part by weight of dry lime) and standard sand (three parts). The crushing test shall be made on 2-in. cubes and the tensile strength test on the standard cement briquette. The specimens are stored in air, and may be broken at any period, generally after 3 months.

For testing the *sand-carrying capacity of lime*, test-pieces are made by using varying proportions of standard lime paste equivalent to a definite quantity of dry lime and standard Ottawa sand. The test is made just like the crushing test.

The Vicat needle is used to determine the *time of set*, and is employed as in cement testing.

For testing *hardness* a sand blast is sometimes used. The Bureau of Standards has recently used a method in which 1,000 g. of BB lead shot are allowed to drop from a reservoir through a 1-inch iron pipe 6 ft. $\times 10\frac{3}{4}$ long on a mortar placed at an angle of 45° with the vertical axis of the pipe. The loss in weight of the mortar due to the impact and wearing action of the shot determines the hardness.

Colour can be obtained by comparison with known standards, which may be made by mixing any pure white powder such as ground calcite with definite amounts of brown colouring matter.

About the only method of judging plasticity is the purely empirical one of spreading over a surface by an experienced operator.

Determination of free calcium oxide or hydroxide.—The following methods are used in the laboratories of chemical manufacturers.

By titration with standard HCl.—This is the oldest and simplest method. Weigh 28 g. of the coarsely ground sample into a litre flask containing about 250 c.c. of recently boiled distilled water. Boil for 10 minutes, close with a cork containing a 6-in. capillary tube and allow to cool somewhat. Make up to the mark and mix well. *Immediately* after mixing draw off 50 c.c. of the milk of lime and titrate at once with normal HCl, using phenolphthalein as an indicator. Allow the flask to remain some time to see if the pink colour returns. For the percentage of free calcium oxide multiply the number of c.c. required by 2.

In the case of hydrated lime use a 1·4 g. sample, place in an Erlenmeyer flask with 250 c.c. of water and titrate the entire volume after boiling and cooling as above. In the case of quicklime the larger weight is necessary in order to get a proper average. The sample should be quickly ground and placed in a tightly corked bottle.

The *Scaife method* is a modification used by chemists of the Scaife Company: Weigh 1·4 g. of the carefully prepared and finely ground lime into an

8-oz. assay flask, add about 80 c.c. hot water, cover with a beaker, carefully heat and then boil for 3 minutes. Cool, remove cover, add 2 drops phenolphthalein and titrate with normal HCl, adding the acid rapidly in a thin stream while shaking constantly to avoid local excess of acid. Near the end drop in the acid rapidly while shaking until the pink colour disappears. Note the reading, but ignore any return of colour. Repeat the experiment adding about 5 c.c. less acid than before, call the number of c.c. used *A*. Grind up any small lumps with the round end of a thick glass rod, transfer the pink mixture to a 250 c.c. volumetric flask, dilute to the mark with distilled water, mix, let settle half-an-hour. Titrate 100 c.c. slowly with phenolphthalein and normal HCl until colourless. Call this additional number of c.c. used *B*. Then percentage of available calcium oxide $=2A+5B$.

By titration with oxalic acid.—In Lunge's "Technical Chemists' Handbook" is the following method for determining calcium oxide in quicklime: "Weigh 100 g. of an average sample carefully taken, slake it completely, put the milk into a half-litre flask, fill up to the mark, shake well, take 100 c.c. out, run it into a half-litre flask, fill up, mix well, and employ 25 c.c. of the contents, equal to 1 g. of quicklime for the test. Titrate with normal oxalic acid and phenolphthalein as indicator, adding the acid very slowly and shaking well after each addition. The colour is changed when all free lime has been saturated and before the $CaCO_3$ is attacked. One c.c. normal oxalic acid $=0{\cdot}02805$ CaO." Lunge also gives the following *method for carbon dioxide*: "Titrate CaO and $CaCO_3$ together by dissolving in an excess of standard HCl and titrating back with standard alkali. By deducting the CaO estimated as above the quantity of $CaCO_3$ is obtained."

By sucrose solution.—G. L. Spencer gives the following method for determining the calcium oxide in quicklime in his "Handbook for Cane Sugar Manufacturers." Add about 30 c.c. water to 10 g. lime in a mortar. Add excess of pure sucrose as a solution of 35—45° Brix and mix it intimately with the lime, which forms a soluble saccharate. Transfer all to a 100 c.c. flask, using a sugar solution of above composition to wash the last portions from the mortar and to make the volume to 100 c.c., mix and filter. Titrate 10 c.c. of the filtrate with a normal solution of HCl, using phenolphthalein or lacmoid as an indicator. The burette reading $\times 0{\cdot}028=$ the weight of calcium oxide in 1 g. of the lime, and product $\times 100=$ percentage of calcium oxide.

Solvay method.—This was devised by chemists of the Solvay Process Co., and is very reliable. A special flask or bottle is necessary, which is cylindrical in shape, with a slight bulbous expansion at the bottom. The bulbous expansion is 2·1 inches high and the same in diameter, the upper cylindrical portion is 4·5 inches long (including the narrower neck) and 1·5 inch in diameter, the base being also 1·5 inch. The neck, which tapers slightly from above downwards, is 0·9 inch diameter at the bottom, and 0·7 inch in length. There are two marks on the bottle, a lower one (129·0 c.c.) 2·3 inches from the bottom, and an upper one (178·6 c.c.) 2·6 inches from the top, the distance between the two being 1·7 inch. Boil 4 g. of the lime ground to pass a 100-mesh sieve in a 250 c.c. Erlenmeyer flask for a few minutes with about 60 c.c. water to thoroughly disintegrate it. After cooling, transfer to the lime bottle, filling up to the lower mark (129 c.c.) with water, then to the upper mark (178·6 c.c.) ammonium chloride in a litre of water. Mix thoroughly by inverting about 30 times. Do not mix afterwards or results will be too high. Let settle from 15 to 20 minutes, draw out 50 c.c. of the clear liquid with a pipette and deliver with stirring into a slight deficiency of normal HCl and about 150 c.c. of water. For 90 per cent. lime, deficiency is 30 c.c. normal HCl, for 65 per cent. lime, deficiency is 20 c.c. normal HCl. Titrate to the end-point using methyl orange as indicator. The number of c.c. of normal HCl multiplied by 2·5 gives the percentage of active (available) CaO.

By converting sodium carbonate to sodium hydroxide—This is used by the chemists of some plants in which lime is used to causticize soda. Weigh 5 g. of the sample into a 500 c.c. flask and add 200 c.c. of approximately normal sodium carbonate, or 10 g. of sodium carbonate and 200 c.c. of water. Close with a stopper having a Bunsen valve in it or a 6-inch tube drawn out to a

thin point and boil for half-an-hour. Add 10 g. of barium chloride dissolved in a little water and make up to the mark with cold water. Stopper tightly and mix well. Allow precipitate of calcium carbonate and barium carbonate to settle. Draw off 100 c.c. of the clear solution and titrate with normal HCl. The number of c.c. of acid used multiplied by 2·8 is equivalent to the percentage of free calcium oxide in the sample.

Blattner's method for estimation of the percentage of caustic lime in milk of lime by means of the *specific gravity* is only suitable for very rough work, and is also given in Lunge's Handbook. Thin milk of lime is poured into the cylinder and the reading of the hydrometer is taken quickly before the lime subsides. For thick milk of lime use a somewhat wide cylinder, put the hydrometer in without using any force and turn the cylinder slowly round, so that it receives a slight shaking until the hydrometer ceases to sink. The following table is valid for 15° C.

AMOUNT OF LIME IN MILK OF LIME.

(Calculated from Blattner.)

Degrees Twaddell	G. CaO per litre	Lb. CaO per cu. ft.	Degrees Twaddell	G. CaO per litre	Lb. CaO per cu. ft.
2	11·7	0·7	28	177	11·1
4	24·4	1·5	30	190	11·9
6	37·1	2·3	32	203	12·7
8	49·8	3·1	34	216	13·5
10	62·5	3·9	36	229	14·3
12	75·2	4·7	38	242	15·1
14	87·9	5·5	40	255	15·9
16	100	6·3	42	268	16·7
18	113	7·1	44	281	17·6
20	126	7·9	46	294	18·4
22	138	8·7	48	307	19·2
24	153	9·5	50	321	20·0
26	164	10·3	—	—	—

BRITISH SUPPLIES OF POTASH-FELSPAR.—P. G. H. Boswell (*J. Soc. Glass Tech.*, 2, 35, 1918). The subject was considered chiefly from the glass-making point of view. The mineral resources of potash consist of (*a*) soluble salts, most abundant at Stassfurt in Germany, but also occurring in many other localities, though not in the United Kingdom in workable quantities, and (*b*) insoluble compounds, which are all silicates except *alunite*, this being a double sulphate of aluminium and potassium [$K_2SO_4.Al_2(SO_4)_3.H_2O$]. *Alunite* and *leucite* ($K_2O.Al_2O_3.4SiO_2$) are not known to occur in quantity in the United Kingdom, but other silicates containing potash, *felspars*, *micas*, and *glauconite*, are abundant. White micas, being often a "resting stage" in the decomposition of felspars, are very stable minerals, from which potash is extracted with difficulty. Neither mica nor glauconite is used directly in glass-making. British and American glauconites contain only 1 to 4 per cent. of potash, but some Continental glauconites contain much more.

Potash-felspar has three chief uses in industry, as a source of both potassium and aluminium for certain kinds of glass, for making pottery glazes, and for the "body" of special wares such as that used for electric insulators. In glazes potash is preferred to soda because it is less liable to crystallize.

The potash felspars, *orthoclase* and *microcline*, differ only in physical properties and crystal form, both being silicates of aluminium and potassium corresponding to the formula $K_2O.Al_2O_3.6SiO_2$. Corresponding to microcline is the soda-felspar, *albite*, $Na_2O.Al_2O_3.6SiO_2$, and isomorphous with albite is the lime-felspar, *anorthite*, $CaO.Al_2O_3.2SiO_2$. Various intermediate combinations occur. Only exceptionally does orthoclase or microcline occur in large enough crystals to be commercially worked, and rocks containing such coarse crystals are known as *pegmatites*, and are usually found in dykes or veins. Pegmatites consist of the same minerals as granite, namely, quartz,

felspar, and white or brown mica, with sometimes a little *hornblende* or *tourmaline*. The varieties sought for their potash contain little else but felspar and quartz, even the latter being subordinate.

Potash-felspar contains theoretically 16·9 per cent. of potash (K_2O), granites may contain 7 per cent., felsites (fine-grained equivalents of granites) 9 per cent., pegmatites about 8 to 10 per cent., and orthoclase and microcline from pegmatites rarely more than 13 per cent. of potash.

Weathering of granites, pegmatites, and similar rocks, results in decomposition of the felspars, the potash being gradually leached out and china clay produced, but an intermediate "resting stage" is often attained, where part of the potash has disappeared and the more stable white micas are formed.

For pottery purposes it is desirable that the felspar or the pegmatite containing it should satisfy the following requirements:—(1) High content of potash, more than 10 per cent. if possible, and certainly not less than 8 per cent. (2) Low content of soda, not more than 2 per cent. (3) Low content of quartz, which should not exceed 5 per cent. for the best work. For inferior pottery the quartz may reach 20 per cent. (4) Iron oxide, if present, should be very low. In the best pegmatites it is less than 0·1 per cent. (5) Lime, if present, should not exceed 0·5 per cent. (6) The felspars should not be kaolinised, for if the rocks be not fresh the potash-content will be reduced.

Scandinavian felspars and several British felspars satisfy these requirements, and many British supplies would become available if rather more quartz be permitted. 13, 12, 11, 10, and 9 per cent. of potash indicate respectively about 77, 71, 65, 59, and 53 per cent. of microcline or orthoclase in the rock. 1, 2, or 3 per cent. of soda in pegmatite indicates about 9, 17, or 25 per cent. of soda-felspar respectively. Pure soda-felspar finds a good market in the enamel industry.

If felspar is to be extensively used in glass manufacture the following desiderata are tentatively suggested:—(1) Constancy of composition, which is difficult to attain. Pure alumina and potash will probably continue in use for the best glassware (2) If the felspar be added to supply potash as well as alumina, the potash should preferably be above 9 or 10 per cent. (3) When potash is required, the soda in the felspar should be low. Although not actually harmful, as in pottery-work (on account of its slightly different chemical properties), it would be expensive to use soda in that form. The soda content is therefore usually below 3 per cent. When the felspar is used, as in the manufacture of bottles, as a source of alumina, a pure soda-felspar could be used. (4) The iron content must be low (though not necessarily as low as 0·1 per cent., especially in bottle-making). Such minerals as *tourmaline* (*schorl*), *biotite*, and *hornblende* should be absent. (5) The felspar should be fresh. (6) The quartz should be as low as possible, from considerations of cost.

Orthoclase may contain a little soda molecularly replacing potash, but in British samples it is not usually intergrown with soda-felspar. But soda-felspar is often intergrown with microcline to produce *perthite*, so deposits of microcline felspar are more liable to vary in the potash-content than is the case with orthoclase.

The veins and dykes of pegmatite in Cornwall contain orthoclase but no microcline. The pegmatites of Western Scotland and Ireland contain microcline, but no orthoclase that the author has seen.

Pegmatites of Cornwall, Scotland (Sutherland), and Ireland (near Belleek, Glenties in Donegal, and Belmullet in Mayo) are described.

A brief account is also given of several felsites and glauconitic sands as possible materials for extraction of potash. Some of the felsites seem promising enough for this purpose, but British glauconitic sands unfortunately have low potash-content. As glauconite is fairly easily decomposed it is suggested that such sands might be used with advantage for supplying plant food. References are given to some of the recent processes for recovering potash from felspar. In an addendum some other pegmatites, etc., in Scotland are briefly referred to.

III.—THE COMPOUNDING & PREPARATION OF CLAYS AND BODIES.

MANUFACTURE OF CHEAP EARTHENWARE.—A. Teichfeld (TRANS., 16, 1, 1917). Relates to the lime-earthenware of Russian Poland and South-western Russia, which is similar to that of the Magdeburg district of Germany.

ACID AND BASIC FURNACE LININGS.—J. E. Foster (TRANS., 16, 24, 1917). Includes an account of the general methods of production of some important refractory materials (bricks of fireclay, silica, magnesite, and chromite).

NEW PROCESSES OF MANUFACTURING FIRECLAY AND SIMILAR ARTICLES.—B. J. Allen (TRANS., 16, 134, 1917). A description of casting processes in which plaster moulds are used in conjunction with vacuum chambers, and also with an electric current.

STUDY OF THE BONE CHINA BODY.—W. H. Yates and H. Ellam (TRANS., 17, 120, 1918). The results of trials made with a view to ascertaining the colour of the products are tabulated, and some are shown by means of a coloured triangular diagram.

MICROSCOPIC STUDY OF THE BONE CHINA BODY.—H. B. Cronshaw (TRANS., 17, 153, 1918). An account of the micro-structure of thin sections of a variety of fired mixtures.

USE OF SULPHURIC ACID IN THE SEDIMENTATION OF KAOLINS.—H. G. Schurecht (*Trans. Amer. Cer. Soc.*, 19, 130, 1917). An account of a study of the effects of adding sulphuric acid to neutralize the sodium hydroxide used to cause deflocculation of the kaolin slip. Florida, Georgia, and North Carolina kaolins were tested. In the case of the Florida and North Carolina kaolins the viscosity after neutralizing the sodium hydroxide with sulphuric acid equivalent was greater than before adding the sodium hydroxide. To reduce this increase in viscosity a somewhat smaller amount of acid should be added. In the case of the Georgia and Florida kaolins the sedimentation was much slower after treatment with alkali and acid than before treatment.

Black discoloration on the dry kaolin is in some cases caused by adding an excess of sulphuric acid. In most cases an amount of acid less than the equivalent of the sodium hydroxide is satisfactory.

The deflocculated kaolin in each case could not be filtered, but when the kaolin was partly neutralized by adding sulphuric acid to the slip it could be filtered readily. The rate of disintegration in water was much slower for the deflocculated kaolin than for the untreated kaolin.

SALT IN THE PURIFICATION OF CLAYS.—H. G. Schurecht (*Trans. Amer. Cer. Soc.*, 19, 460, 1917). Account of investigation on the relation of salt to clay in the purification of clays, based on the effect of alkalies on the viscosity of clay suspensions (slips). Georgia kaolin and Kentucky ball clay were used, the effects of sodium hydroxide, sodium silicate, and sodium carbonate being ascertained. The following conclusions were reached for cases where the water is relatively pure: While the chemical activity of the electrolyte on clay may be slightly less in the more concentrated solutions than in the dilute solutions, the keeping of the ratio of electrolyte to clay constant is much more important in maintaining minimum viscosity in clay slips in which the clay and water contents vary, than keeping the ratio of electrolyte to water constant. With sodium hydroxide and Georgia kaolin the decrease in viscosity is retarded up to a certain point when small quantities of alkali are added, and then when more is added there is a sudden drop to minimum viscosity. When sodium carbonate or sodium silicate are used in the place of sodium hydroxide the decrease in viscosity is not retarded in that manner. Sodium silicate and sodium hydroxide are found to be much more effective

reagents to produce a decrease in viscosity than sodium carbonate, as Bleininger also found. The limits within which sodium hydroxide produces minimum viscosity are small, while the limits within which sodium silicate and sodium carbonate produce minimum viscosity are relatively large. The viscosity data indicate that 50—58 per cent. more clay could be treated when alkali sufficient to produce minimum viscosity is added than when no alkalies are added, but trial on a commercial scale is necessary.

FLOW OF CLAY THROUGH HOLLOWWARE DIES.—G. D. Morris (*Trans. Amer. Cer. Soc.*, 19, 479, 1917). A short discussion of the effects of pressure and construction of dies on the flow of clay, based on experience with 3 shales and 2 fireclays.

WET CLAY ELEVATOR.—G. D. Morris (*Trans. Amer. Cer. Soc.*, 19, 484, 1917). A descriptive account of bucket elevators, with instructions for preventing the clogging up or tearing off of buckets.

PREPARATION OF CLAYS, MINING, DRYING, AND PROPER MIXING.—W. W. Swengel (*Claywr.*, 68, 235, 1917). Many failures of brick plants are attributed partly to want of proper attention to the scientific preparation of clays and shales.

It is pointed out that the ordinary methods adopted by many large plants of using mechanical devices for getting clay from the clay pits, and assuming that a satisfactory mixture is thus obtained at all times, is the source of much trouble. The usually varying thicknesses of the different beds causes changes in the mixture, and this uneven mixture often results in loss of value in the bricks produced which more than counterbalances the saving effected in the actual mining operations.

Non-plastic clay or shale, if allowed to age after being ground, is improved as regards working qualities. Sometimes trouble in this way is caused by the presence of too much sand (from the overburden, or pockets, or veins), in which case ageing would be of little use; it would then be easier and cheaper to use more care in the selection and mixing of the raw materials than to have large storage bins.

It is just as important in many cases to have a clay drier for drying damp clay, so as to be able to eliminate pebbles, to enable the plant to make proper and exact mixtures, and to enable the plant to maintain a maximum capacity, as it is to have down draught kilns to burn the bricks in.

The irregular mixture of clays causes difficulty in pugging.

In the case of paving bricks, variations in porosity and density arise from changing consistency of the mixture and from varying proportions of plastic and non-plastic material. Much of the trouble caused by lamination in paving bricks originates from these causes. To avoid such troubles each clay or shale should be mined separately, dried and screened, then mixed mechanically in exact proportions, and the water also properly regulated.

PINHOLING AND PEELING ON TERRA-COTTA.—H. Wilson (*Trans. Amer. Cer. Soc.*, 19, 209, 1917). An account of peculiar pinholes resulting from small tongues or underslip rising through the glaze and leaving a clean hole to the body.

Two per cent. gum arabic sorts added to the underslip and 3 per cent. added to the glaze stopped all pinholing. When the gum is omitted from either the slip or glaze a few pinholes appear at times. The gum increases the slip strength and stickiness to such a point that the soluble salt action, surface tension of gas expansion cannot break the surface. Besides the elimination of the pinholes, the gum causes the underslip to hold tight to the body during the dry stage. Also the glaze surface is hardened and is not easily broken nor dusted off in kiln setting. The ball content which had been relied upon for holding the glaze and slip to the body could be reduced.

The souring and fermenting on standing is a bacterial action and tends to destroy the holding quality of the glazes. It can be stopped with formaldehyde, or other disinfectants.

CAUSES OF FAILURE OF TERRA-COTTA IN THE WALL.—R. L. Clare (*Trans. Amer. Cer. Soc.*, 19, 593, 1917). The causes discussed include defective body mixtures, defective glaze or slip coating, irregular burning conditions, and the manner of setting the material in the kiln.

PAVING BRICKS FROM BLAST FURNACE SLAG.—J. B. Shaw (*Trans. Amer. Cer. Soc.*, 19, 507, 1917). It is claimed that American slags can be used for making satisfactory paving bricks. The molten slag is transferred to a frit furnace along with silica (sand), alumina, china clay, iron oxides, calcium carbonate or magnesium carbonate, and in less than 30 minutes bricks can be cast by running the molten mixture into moulds. The bricks are afterwards set in small hot annealing furnaces. Slag alone makes very brittle bricks unless they are cooled very slowly (as by burying the bricks in sand). The use of iron oxide with the slag gives good tough bricks, but they are black. The annealing must be done out of contact with the air.

THE BRITISH SPELTER INDUSTRY. MANUFACTURE OF ZINC RETORTS.—(*Engineering*, 105, 167, 200, 1918). A general review, with trade statistics. Reference is made to the new department of William Johnson & Sons (Leeds), Ltd., for the construction and equipment of spelter works plant. The plant includes the pugging and preparing machinery for preparing the raw fireclay, etc., and a special type of hydraulic press in which the retorts are moulded and finished, together with the necessary pumps and accumulators. Messrs. Johnson manufacture general clay-working machinery (grinding and mixing plants).

The general arrangement of a zinc plant is shown in a plan, including the retort furnaces for zinc-distillation, and the producer-gas furnaces for feeding them, and the clay and retort departments. These latter comprise clay stores, drying and maturing rooms, rooms for grinding and mixing the retort materials—fresh and also old fragments of used retorts so far as utilisable for the making of adapters, etc.—and the pugging, drying and baking rooms for the retorts. The ordinary treatment of zinc-blende and other zinc ores is described briefly.

The ground roasted zinc oxide, which still contains some sulphide and sulphate, silicates and the other metals, is mixed with fine coal and reduced in retorts at temperatures between 1,100° C. and 1,300° C. It ought to be possible to effect the reduction at lower temperatures and higher pressures, or, with the aid of catalysts, at ordinary pressure. Practically the reduction has not so far been successful in shaft furnaces, because the zinc vapour, when strongly diluted with CO and CO_2, will not liquefy, but will condense as zinc dust. Experimenting with shaft and reverberatory furnaces continues. Meanwhile the reduction proceeds in tubes, muffles or retorts, and it is far from being perfect, losses of 10 to 15 and even 20 per cent. of zinc being hardly avoidable.

The manufacture of the retorts requires great care, and has to be effected in the works, since the finished retorts cannot be transported. The ordinary raw material for the retorts over here was a mixture of good clay, Belgian and English, both well-matured raw clay and the burnt material; since the outbreak of the war retorts have successfully been made by mixing various qualities of English clay. High-grade silica clays are used in Silesia. The plant for preparing the clay consists of a jaw crusher discharging into a disintegrator, whence the ground clay is elevated to a $^3/_{16}$-mesh screen suspended over a hopper of 10 tons capacity. From the hopper the material passes into a conveyor, and is then fed into a 6 ft. differential mixer, and then it passes on to a 12 ft. pug mill, placed at right angles to the mixer; here it is rendered plastic enough for pressing.

Double mixing is necessary for intimately mixing the grog and raw clay before being pugged so as to ensure a sound retort. After pugging the clay is left in a maturing room for several days. It is then elevated to the vertical pug and ballot maker. The ballots of clay are cut to suitable lengths and transferred to the press. The various contrivances are illustrated.

The retorts are made of various shapes, round and oval, with flat bottoms like gas retorts, etc. In the older methods the mould was filled with clay, and the clay then hollowed out with a drill. The modern practice prefers hydraulic presses. In Mahler's press (introduced in 1883) one central hydraulic cylinder is surrounded by two smaller cylinders, the rams of which carry pistons which enter the mould chamber above the cylinders. (In the Dor-Delattre press there are four smaller cylinders). This chamber is closed by a cover, under which lies the annular die which gives the retort its external shape. After loosening the bolts with the aid of the levers, the cover and the annular die can be turned about the rod (on the left), so that the lump of clay can be dropped into the chamber. The cover is closed and the hydraulic pressure turned on. The central ram, being larger than the others, alone rises first and forces its piston up through the clay. The piston bears on its top a die which determines the internal section of the retort, the back of which is formed between the cover and the two dies. The pressure is now cut off momentarily, the cover turned sideways once more, and the pressure is put on again. The two small rams then move; they had so far been kept down, together with the piston they actuate which surrounds the main piston like a cylinder. As this ring piston rises it forces the clay through the annular port between the inner and the outer die, so that the retort tube projects from the chamber to the desired height. When this height is reached the length of soft clay retort is cut off with a brass wire. To guide and protect this soft mass a hood is suspended above it by means of a balance-weight.

After the retort is pressed it is transferred into drying and maturing rooms—each room being sufficiently large to hold 500 retorts or thereabouts. The drying or maturing of the retorts takes about three months. The trade practice is to allow these retorts to remain in the maturing room longer than this if at all possible. The well-matured retorts when required for use are annealed in kilns, prior to their being charged to the furnace, to a temperature approximately equal to that of the combustion chamber in which they are to be placed. The retort dimensions vary much; lengths of 150 cms. (about 5 ft.), heights of 20 or 35 cms. (8 or 14 in.), wall thickness of 20 to 30 mm. ($\frac{3}{4}$ to $1\frac{1}{4}$ in.) and weights of 75 kg. (about $1\frac{1}{2}$ cwt.) may be averages.

The condensers for the retorts are known as adapters or prolongs, nozzles or collectors. The adapters are doubly-conical or belly-shaped clay tubes, also made by machinery now, and luted into the retort when *in situ*; the zinc vapour is liquified in the adapter. In front of the adapter, and held there by wires, is the collector or nozzle, which is generally made of sheet iron and is provided with partitions so as to catch the pulverulent zinc fumes or dust. The Steger nozzle, which resembles an upright Z, has given satisfaction in Silesia; from the upper nozzle end a pipe extends into a flue in which the CO is burned. The molten zinc is scraped out of the adapters into a casting ladle and run into a mould. The slab or ingot produced weighs on the average 44 lb.

In the furnaces several tiers of retorts rest slightly inclined with their backs on ledges; double furnaces consist of two parallel rows of retorts, of which there may be a thousand in one furnace. Double furnaces (with 120 retorts) shown in illustrations are gas-fired with producer-gas on the regenerator principle and seem to be designed for a uniform distribution of temperature about the retorts. Two main flues run along the furnace, but not directly underneath the bottom tier, which was overheated in some types of furnace.

In older types the retorts of the different tiers were not all of the same dimensions, nor at the same angles.

Furnaces with 4, 5 or 6 tiers of retorts need movable platforms for the workmen to manipulate the higher tiers, and in order to avoid extra labour additional plant and structural work becomes necessary.

Smelting costs would probably be considerably reduced (as regards charging and discharging, etc.), by the adoption of vertical retorts, but it is yet to be proved that the distillation could then be made continuous. With the horizontal retort furnace the campaign takes about 24 hours, $\frac{1}{2}$ to 1 hour for renewal of retorts left defective from the previous campaign, 2 hours for

discharging the residue of the previous distillation, 2 or 3 hours for introduction of the new charge including the fixing of the adapters and luting, etc., leaving only 18 hours for the distillation. In the vertical retort these operations might be greatly accelerated, giving about 22 hours for the distillation. It may be argued that the zinc fumes would not penetrate through a dense charge in a vertical retort, and that the slag formed in the hottest zone would tend to retain the zinc. But difficulties might be overcome in the case of fine ore by intimately mixing the roasted product with the reducing material, and making briquettes of convenient size and shape.

CHAMOTTE PRODUCTS.—F. H. (*Ker. Rund.*, 23, 259, 275, 1915). Has particular reference to the emery industry, but may have wider applications. An illustrated description is given of the manner of setting emery wheels in the oven, including the saggars and slabs, etc., used as supports. Mixtures for making saggars are also alluded to. Dust grog is condemned, and the coarse, medium, and fine-grained grog are to be used according to the size of the saggars in other pieces made. Quartz should not be used to mix with the fireclay because of its behaviour on heating. Care must also be taken to secure uniform moistening of the mixture by well moistening every layer of grog put down, and draining after standing for at least a day. The mixture must not be worked too wet. For small saggars up to about 14 inches (350 mm.) diameter, pressed saggars 1 inch (25 mm.) thick have proved very satisfactory. Too rapid cooling (as well as too rapid heating) of the saggars is to be avoided.

The following mixtures have been tested and found satisfactory:

(1) Wildstein clay 10, Wiesau clay 20, Halle clay 20, Chamotte 50.
(2) Raw kaolin 20, Halle clay 30, Chamotte 50.
(3) Wildstein clay 20, Wiesau clay 40, Chamotte 40.

As a starting point for trials may be taken: Raw kaolin 20, fat clay 40, and Chamotte 40.

FINE GRINDING OF BODIES AND GLAZES.—C. Tostmann (*Ker. Rund.*, 23, 145, 153, 179, 196, 1915). Controversial articles in which the author, W. Pukall, and E. Conrad take part. They begin with a critical review of Pukall's articles in *Sprechsaal* on "Ceramic Working Bodies." (See TRANS., 16, *Abs.*, 102, 1917).

TERRA-COTTA.—L. H. Minton, U.S. Pat. 1,228,465, June 5th, 1917. An unvitrified terra-cotta, highly resistant to weather, is produced from 30 parts of stoneware clay, 30 low grade fireclay, and 40 slag (highly siliceous, but low in lime and particularly free from iron).

VARIEGATED TERRA-COTTA.—W. E. Dennison, U.S. Pat. 1,228,538, June 5th, 1917. Architectural terra-cotta is produced by dashing into a mould portions of differently coloured clays while in a plastic condition, subjecting it to pressure, leaving it to dry by evaporation of the moisture, removing from the mould and finally burning.

SANDSTONE BODIES.—W. Pukall (*Sprech.*, 46, 1, 1912). In order to make bodies similar to old Persian tiles, old Egyptian ware, and tiles in the Omar mosque in Jerusalem, which are composed of alkaline but non-aluminous sandstone (not clay), the author recommends a mixture of 100 parts of fine sand, 9 of soda crystals, 12 of water-glass (sp. gr. 1·38), and 4 of water. The mass is shaped by hydraulic pressure, and on burning at cone 05 contracts 4·7 per cent. At higher temperatures the contraction increases to 8·8 per cent.

IV.—SHAPING AND MOULDING. DRYING.

PROMENADE TILES.—M. W. Blair (*Trans. Amer. Cer. Soc.*, 19, 361, 1917). Notes on the manufacture of stiff-mud floor tile (now generally called "promenades" when 6 in. × 9 in., or "quarries" when 6 in. × 6 in.), with

special reference to initial difficulties met with and the measures adopted to overcome them.

EFFECT OF VARIATION OF PRESSURE IN THE FORMING OF DUST PRESSED TILES.—F. K. Pence (*Trans. Amer. Cer. Soc.*, 19, 94, 1917). Account of an investigation to determine relation between pressure and (1) density, (2) shrinkage, (3) glaze fit, in typical tile bodies under normal conditions of manufacture, and also to determine practical limits of pressure. The tests were made on porous body for bright white-glazed wall tiles (fired to cone 10), semi-vitreous or red floor-tile body (fired to cone 7), and vitreous or white floor-tile body (fired to cone 11), containing 9½, 7½ and 10 per cent. of water respectively. Drying shrinkage was negligible. The average results for the extreme pressures of 107 to 4,800 lb. per sq. in. were as follows, the shrinkage across face of tile being given.

Pressure	Vitreous		Semi-Vitreous		Porous	
	Absorption	Shrinkage	Absorption	Shrinkage	Absorption	Shrinkage
107	6·514	14·19	16·700	8·82	25·116	4·96
4800	0·003	7·19	4·063	4·62	8·738	3·18

The figures are given as percentage of original dimension. The effect of pressure upon shrinkage is very marked. The shrinkage curve follows the absorption curve, showing greatest range of values in vitreous body and least in porous body. The general agreement of the curves for the three types is noted. The volume shrinkage of the tiles did not change materially since tiles remained thicker with reduced pressure. The form of the curves shows that the point where further increase in pressure does not produce a proportionate increase in density is about 800 to 1,000 lb. per sq. in. In the glazing test for porous body the difference between the various members was not marked.

Crazing of soft biscuit tiles would signify "soft" biscuit fire, and not "soft" pressed only. In practice it is found that in curved shapes those parts that tend to receive least pressure when tile is being pressed are the parts that show greatest tendency to shivering of the glaze.

Under practical conditions the lower limit of pressure seems to be about 1,000 lb. per sq. in., while upper limit might be 2,400 or more, depending upon possible difficulties as to bursting or splitting of the tile in pressing, or blistering of vitreous body in firing. In general a better surface texture results from higher pressure.

A pressure of 1,800 to 2,000 lb. per sq. in. seems advisable as a satisfactory mean, permitting of considerable variation of pressure in either direction without seriously impairing the quality or uniformity of the tiles.

HUMIDITY IN RELATION TO DRYING OF CLAYWARES.—W. A. Denmead (*Trans. Amer. Cer. Soc.*, 19, 538, 1917). A lengthy discussion of the question of control of humidity, and its relation to the drying of claywares, particularly electrical porcelain. The importance of relative humidity—or ratio between the actual moisture content of the air and the greatest possible content at the same temperature—is emphasized. Relative humidity is usually expressed as a percentage. Illustrations of various appliances are given, which have proved very satisfactory in textile mills and many other plants, and though the author's experience does not enable him to state just how successful the control devices are, he found that wonderful results can be achieved under correct conditions, and adds that the success of drying with artificially moistened air depends entirely upon an understanding of drying phenomena and the efficiency of the automatic control apparatus.

The more important conclusions arrived at include the following: Drying takes place more rapidly the lower the relative humidity at the same temperature, or the higher the temperature with the same relative humidity. A safe relative humidity for one ware may not be safe for another. The relative humidity in general increases slightly from the ceiling to the floor. Allowances must be made for escaping moisture, which is unavoidable with any system of ventilating buildings. A system capable of maintaining different humidities at different spots is desirable, as many designs can be dried much more rapidly than others. Ware heated to a high temperature (say 150° F.) with nearly maximum humidity, can be safely dried much more rapidly than if heated to a lower temperature at the same relative humidity or at the same temperature at a lower relative humidity. The evidence seems to indicate that time lost in slower first stage drying is more than compensated for by the greater possible speed in safely drying the ware during the second stage. Most ware cannot be cooled rapidly even though bone dry, without risking loss on drawing.

For most ware it is not necessary or desirable to reduce the moisture content of the ware below 1½ to 2 per cent., and it is expensive to do so. All leather-hard pieces examined shrink only a few per cent. in drying, and that shrinking takes place with the elimination of the first few per cent. of moisture. The success of the system depends upon the operation of the automatic regulating devices for temperature and humidity. For the first stage in drying temperature control is seldom essential. The opening of windows in the shop while the humidifying system is operating will upset the regulation, but when windows can be safely opened the humidity control is usually unnecessary. It is suggested that the creation of draughts through opening windows causes considerable loss under any conditions, except under very careful attention, and that opening a window would not produce any more serious consequences with humidity control than without. Movement of air is essential in most cases to limit variations in humidity. Dehumidifying the drying room air for first stage drying is suggested as desirable in certain cases where high natural humidities regularly prevail for considerable periods in summer.

The author mentions that the safe drying in 12 hours was repeatedly accomplished on one of the most difficult pieces, which often shows considerable loss in air drying for one month under presumably favourable conditions. In the humidity dryers the drying of wares has been reduced from 8 and 9 weeks to 1 week. Magnesia bricks have been similarly dried with an enormous reduction of time. It is essential to keep air moving in order to avoid condensation, especially when humidity exceeds 65 or 70 per cent.

TERRA-COTTA MOULD MAKING.—R. B. Keeler (*Trans. Amer. Cer. Soc.*, 19, 585, 1917). An account of recent improvements.

CASTING PEDESTAL CLOSETS.—Wolf (*Ker. Rund.*, 23, 115, 127, 147 171, 189, 1915). See TRANS., 15, 149, 1916.

PRODUCTION OF STONEWARE GOODS.—W. Breitwieser (*Ker. Rund.*, 23, 201, 221, 233, 1915). All stonewares are made of clay mixed with felspar and sand or grog, and the body is strongly burned, well sintered, and impermeable to water. They are highly acid-proof and generally salt-glazed. The general process of preparation is described for making tubes, etc.

The rational composition of stoneware is given as about 40—50 per cent. clay substance, 35—45 per cent. quartz sand or grog, and 20—27 per cent. felspar. The clay substance is introduced in the form of plastic stoneware clays (mixture of fat and lean). Other clays may be used instead, along with a larger proportion of felspar.

V.—FIRING KILNS, OVENS, MUFFLES, ETC.

THE DRESSLER TUNNEL OVEN APPLIED TO STEEL-WORKING.—C. Dressler (TRANS., 16, 171, 1917). An illustrated account of this oven as adapted for the heat treatment of steel.

BLACK CORES IN FIRECLAY GOODS.—J. W. Mellor (Trans., 16, 259, 1917). A popular lecture delivered at the Stourbridge meeting of the Refractory Materials Section of the Society.

THE FIRING OF POTTERY OVENS.—S. T. Wilson (Trans., 16, 304, 1917). Presidential address, in which the distribution of temperature and conditions of atmosphere are more particularly discussed. The question of the possibility of using continuous regenerative ovens for firing china or earthenware was also briefly considered.

REFRACTORIES AND MODERN KILNS.—J. G. Maxwell (Trans., 17, 57, 1918. A review of the best known types of gas-fired kilns for refractory goods.

SCHNABEL GAS-FIRING.—H. Beck (*Bericht 32 Ordentliche Hauptversammlung des Vereins deutscher Fabriken feuerfester Produkte E.V.*, 1912, p. 215). The principle of the Schnabel gas-firing is protected by German patent (D.R.P.) 218,918, and, in contrast with the hitherto usual methods of gas-firing, consists in bringing the mixture of gas and air not as flame but flameless for combustion within glowing masses permeable to gases. The practice of this process is not only associated with an extraordinary increase of the temperatures hitherto attained with gas-burning, but also with a better utilization of the heat produced, for the following reasons: 1. Retaining the heat of the burning gases in the stream flowing through the permeable mass acting as mechanical resistance. 2. Storing of heat retained by the permeable mass. 3. Acceleration of the combustion process through catalytic action by contact of the burning gases with the glowing permeable mass. 4. Combustion of the gases under pressure, whereby combustion takes place in smaller volume. To prevent striking back of the flame into the burner it is necessary that the velocity of the flow of the mixture of gas and air should correspond approximately to the velocity of ignition.

Muffles—for ceramic ware, etc.—can very well be laid round and heated with a glowing mass permeable to gas. An important field for employment is the burning and calcining of refractory materials, in which the possibility of rapidly and easily getting up to very high temperatures is very valuable.

A similar invention has been made by Bone, approximately simultaneously and quite independently of the German inventor, and with good practical results.

Other directions in which this method of heating might prove of great advantage are in the chemical industry, boilers, and metallurgy.

IONIDES SYSTEM OF GAS-FIRING.—(*American Machinist*, 47, 42E, 1917). A report of a paper read by Mr. A. C. Ionides at a Meeting of the Institute of Metals. The main variables to be dealt with as regards establishing and maintaining a constant mixture of gas and air are: (1) the inlet pressure of the air, (2) the inlet pressure of the gas, and (3) the variation in consumption of either air or gas that may occur in any given installation. The problem was solved by the aid of a pressure balance or mixture balance, consisting of a sensitive bell with the requisite length of seal. The inside of the bell is subjected to the static pressure of the gas, and the outside to the static pressure of the air, and when the static pressure of the gas increases the arrangement enables the flow of gas to cut itself off, the flow of air being to some extent increased; when the static pressure of the air above increases it shuts itself off and opens the gas correspondingly, and *vice versa* when the gas and air are decreased. A similar cycle of operations takes place when the consumption of the one or the other is increased or decreased. By such a device the pressures of gas and air are always held in a constant ratio, whatever be the variation of either the inlet pressure of gas or air, or the consumption. If a mixture of gas and air be rich in gas, the flame is correspondingly lengthened. If the proportions approach 6 or 7 volumes of air to 1 of gas (according to the quality of the gas), it is quite possible, given silica or any other good catalyser, to have no flame at all, but merely surface combustion.

These conditions present great difficulties in heating with a neutral mixture (neither oxidizing nor reducing) because of the tendency to local heating. If a good catalyser be placed at right angles to a stream of well-proportioned mixture, a glowing disc will be observed, but if all catalysers in front of this stream are avoided the combustion can be spread out to a very considerable length. The author has proved that with a $\frac{3}{4}$ in. injector, or even with one of $\frac{1}{2}$ in., it can be spread out to a length of 3 ft. of almost homogeneous combustion, by putting the injector into a channel of firebrick opened at the top. In this way the heat units can be distributed in a furnace, or boiler, or any other heating apparatus, in a very satisfactory manner.

It was observed that in this system the hotter the furnace grew the less was the consumption of gas. If the mixture enter the furnace at, say, 15° C., and if it behave as a perfect gas, it will expand to 1,700/(273+15), or $5\frac{3}{4}$ times its initial volume.

If the waste gases, instead of passing into a chimney open at the top, are displaced downwardly through a contracted exit of predetermined cross sectional area, this will cause a resistance to the flow of incoming gases and provide the elements of the most refined thermostat, without any working parts. In fact, by these means the temperature to be maintained can be predetermined with a pencil and a piece of paper.

To determine the mixture the simplest plan was found by trial to be to fit an ordinary gas cock with a piece of copper tubing bent with an easy bend and enlarged at the farther end, and screwed into the injector in such a manner that the enlarged opening at the end of the copper tubing faces the central axis of the delivery pipe, in this way avoiding stream lines. If a piece of india-rubber tubing and an incandescent mantle be fed with this mixture, visibility of the meshes of the mantle indicates an oxidizing mixture, the mantle being at its most brilliant point indicates that the mixture is very near the neutral point, whereas the escape of any unburnt gas from the mantle in the shape of a blue flame indicates an excessively reducing atmosphere.

The variable quality of the gas can be provided for by external distribution. Assuming there is a mixing balance on the air and gas mains entering into a factory, and that all the injectors in the factory are properly calibrated and set for their various functions (brass-melting, steel-heating, illuminating, etc.), an unwelcome change in the quality of the gas is immediately visible on one of the lights. A regulating cock on the air main (preferably a screw-down tap) will at once put this right, and the whole of the factory will be compensated for this change in the quality of the gas.

The conditions of conducting heat operations of many kinds on these principles are cleanly, and extremely economical in fuel, as well as in forgings, the ready establishment and maintenance of a reducing or oxidizing flame ensuring absence of scaling; it is stated that scaling has often necessitated the scrapping of 90 per cent. of the steel forgings. In a half-ton billet heating furnace the gas consumption was 1·3 cub. ft. per lb. for full forging heat, the scaling being negligible.

In a 20 lb. crucible furnace for melting brass the gas consumption was 2·75 to 3·98 cub. ft. per lb. of brass melted, from cold. Vickers, Ltd., decided to establish this system throughout their works, after trying it with a barrel-heating furnace 36 in. × 12 in. × 3 in. inside.

A crucible furnace made on these principles has between the inner and outer walls a flue space through which the gases—delivered laterally at the base of the furnace—vent themselves and pass, by way of the hollow platform at the base, through the apertures to the downward discharge pipe. In a barrel-furnace the heating chamber has a door at the front, and jacketing flue spaces above and below and on the greater portion of its sides. The central chamber communicates by one or more circular apertures with the top flue space, and the heating elements pass through the apertures and along the flues, being finally discharged below at a central aperture in the floor of the furnace. In the bricks forming the floor there runs along each of the two sides a narrow combustion chamber, into which a nozzle delivers the gas mixture, and a mixing device is provided, with means for adjusting gas and air. Each

long combustion chamber delivers the products of combustion by means of a long narrow slot into the central combustion chamber. The nozzle is placed at one end of this chamber so that the heating elements, passing along the chamber with upward motion, escape through the slot and enter the furnace chamber with a diagonal movement. The gases tend to turn when they meet the adjacent wall, giving a whirling motion. Arranging the nozzles for two combustion chambers at opposite ends of the furnace will accentuate the whirling action.

A light worked by means of a pressure balance feeding a small incandescent mantle will produce 130 to 150 c.p., with a consumption of under 3 cub. ft. per hour of town gas of standard calorific value; the highest candle-power light obtained at this pressure by other systems averages 22 c.p. per cub. ft. of gas consumed (variable, of course, owing to the atmospheric burner).

A 3-in. pressure balance saves 50,000 cub. ft. of gas, or 5 tons of coal per ten hour day, compared with a Brown and Sharpe furnace, which is considered by all small arms factories to be the best available.

One thousand of these devices, in the manufacture of which 240 tons of combined iron castings and steel sheeting would be required, would save in six months (*i.e.*, 180 ten hour days) the gas from 900,000 tons of coal.

If this system should be found to be equally economical with all forms of producer gas as with town gas, these devices would save half the coal, as compared with the use of raw coal as fuel.

BURNING CLAYWARES.—E. Lovejoy (*Claywr.*, 68, 230, 1917). A discussion of the use of steam for blast. The evaporation from a boiler may be roughly determined by dividing the B.t.u. value of the coal by 970 and taking 70 per cent. of the result. From given data calculations are made to get the calorific value of the gas derived from the fuel and steam. It is concluded that a safe estimate of the average producer loss is 20 per cent., using the gas hot as it comes from the producer. The chief advantage of gas is that it can be burned with very nearly the theoretical percentage of air, whereas coal combustion is often accompanied by a heavy load of excess air. Another advantage claimed for the gas is that the kiln radiation loss is greatly reduced.

RECENT FORMS OF CARBON TUBE FURNACES.—J. A. Harker (*Trans. Faraday Soc.*, 12, 3, 1917). An account of electric furnaces used at the National Physical Laboratory. As regards the insulation of carbon and graphite furnaces, a very flocculent kind of lamp-black, containing very little organic matter, which is used in paint-making, and is said to be made from burnt rags, has always been employed; a layer of this 4 or 5 inches thick radially makes a most excellent insulator, prevents the burning of the furnace parts by accidental access of air, and stops all connection in the internal space, though for a few heatings the lamp-black gives off much gas.

In the course of the subsequent discussion, *Dr. W. Rosenhain* referred to two different types of gas furnace, a Seger-Heinecke furnace (with chimney) with which he had been able to obtain and steadily maintain temperatures well above 1,550° C., and an ordinary cyclone furnace in which he employed a specially made blowpipe burner for use with compressed air at 100 lb. per sq. in., giving temperatures probably up to 1,700° C. *Mr. S. N. Brayshaw* described his burner for mixed gas and air, with which it was possible to melt platinum with only 3 lb. of air pressure. *Mr. C. R. Darling* mentioned that in furnaces wound with nickel-chromium (nichrom) wire, which could be used at 1,000° C. almost indefinitely, he had found insulation by magnesia bricks to give very good results, half a kilowatt sufficing to maintain the temperature in a furnace with a tube 1 ft. long and 1 in. in diameter. An advantage of nichrom was that it could be connected straight to the mains without risk of burning out. *Mr. H. G. Lacell* confirmed Mr. Darling's statement as to the value of nichrom wire or ribbon for the windings of resistance furnaces, and said that a rough-and ready arrangement gave quite satisfactory service, lagged with kieselguhr in a biscuit tin. *Dr. H. C. Greenwood* pointed out that a rougher type of furnace built of bricks and charcoal could be used for many purposes with advantage.

COAL FOR BURNING CERAMIC WARES.—R. R. Hice (*Trans. Amer. Cer. Soc.*, 19, 488, 1917). A discussion of the relation of fusing point of ash to availability of coal for burning ceramic wares. The substances present in the ash are silica, lime, magnesia, iron oxide, alumina, sulphur, oxygen, and other elements in small quantities as accidentals. Pyrites, slate, dirt, bone, coal, etc., are supposed to be thrown out in the mining, but this is not done completely, and parts of the underclay and roof also. There is no apparent relation between the sulphur content of the coal and the quantity of the clinker, or the fusing point of the ash. Samples of coal should be taken in a proper manner, and the fusing point of the ash should be determined, in order to ensure that the ash has at least a relatively high fusing temperature.

HEAT BALANCE OF A CONTINUOUS TUNNEL KILN.—C. B. Harrop (*Trans. Amer. Cer. Soc.*, 19, 216, 1917). An account of the first of four tests conducted by the U.S. Bureau of Standards on a continuous tunnel kiln of the moving car type, at a refractories plant at Keasbey, near Perth Amboy, N.J. The kiln is 197 ft. long with a tunnel cross section 4 ft. 4 in. wide by 8 ft. high.

Four hand-fired horizontal grate bar furnaces are used, two on each side of the kiln, located close together and about 108 ft. from the charging end. The grate area of each furnace is 16½ in. by 39 in. The ash pits are depressed and are kept filled with water. The draught outlet is about 18½ ft. from the charging end of the kiln. Vertical flues (one on each side of the tunnel) in the side walls at this point drop past fireclay slab dampers into the main draught flue, which runs transversely underneath the kiln. This main draught flue (which also serves a second similar kiln) leads to a chimney 126 ft. high by 5 ft. 6 in. diameter inside, the top of which is closed to 5 ft. 6 in. by 15 in.

The ware—consisting of standard firebricks and other refractories—is said to be burned to cone 14, and the distribution of heat through the ware seeemd to be good, though no test was made for this. The tunnel holds 36 cars, 17 heating up, 4 in the high fire zone and 15 cooling at all times.

The test covered a period of six hours, during which time temperature and humidity readings were taken every two hours, the temperature at certain points being taken each hour. Various other observations were recorded, and analyses obtained of the coal and ash, etc. From the data it was ascertained by calculation that (1) 3·27 per cent. of the possible heat from the coal was lost in the ash, (2) 23·3 per cent. of the heat was lost in the dry flue gases leaving the kiln, (3) 0·33 per cent. of the heat was lost in the atmospheric moisture passing out with the flue gases, (4) 1·79 per cent. of the heat was lost in evaporating and heating water from the ash pits, (5) 3·67 per cent. of the heat was lost with the mechanical and hygroscopical water from the ware, (6) 4·22 per cent. of the heat was lost in the water removed from combustion with the clay, (7) 2·52 per cent. of the heat was lost with unconsumed CO in the flue gases, (8) 17·07 per cent. of the heat was lost in the ware and clay supports, etc., on the three cars discharged, (9) 0·20 per cent. of the heat was lost in the ironwork of the cars, (10) 45 per cent. of the heat was lost by radiation and conviction.

GAS-FIRED POTTERY FURNACES.—(*Gas Journal*, 96, 491, 1918). An illustrated description of the "Porceflam" furnace which has been used at the Stoke Pottery School in the research work on hard-paste porcelain. It is fired by town gas at ordinary pressures but preheated, in conjunction with preheated air under very slight pressure (seldom as much as 8 or 10 inches of water, and never more), the admission of both gas and air being under complete control. The recuperation chambers in which gas and air are preheated run the full length of the furnace. The gas is burned in patent "Flamos" burners, which allow the heat to enter the furnace from large mouths instead of small jets, thus lowering the velocity of the currents within the furnace and producing a much more gentle firing action. The construction of the burner with the arrangement of inlet and outlet openings, result in uniform distribution of temperature. It is also claimed that back-firing troubles are entirely avoided.

SETTING WALL-TILES IN THE MUFFLE.—R. P. (*Ker. Rund.*, 23, 9, 1915). An illustrated description of the process of setting glazed wall-tiles. Shaped supports are used for keeping the tiles apart. In another method glazed tiles are arranged alternately with waste biscuit tiles so that each pair make an eight-rayed star. On each corner (uncovered) of the waste tile is placed a small support to keep the next tile resting on it clear of the intervening glazed tile.

TANK FURNACE FOR MELTING IRON ENAMEL.—F. Kraze (*Ker. Rund.*, 23, 23, 1915). A brief description, with illustration. It includes a gas generator and a recuperator.

VI.—GLAZES AND GLAZING. ENAMELS.

EFFECTS OF WATER ON FRITS DURING WET GRINDING.—J. W. Mellor (Trans., 16, 67, 1917). A note on the action of water on alkali-containing frits, etc.

ENAMEL SURFACES UNDER THE MICROSCOPE.—E. P. Poste (*Trans. Amer. Cer. Soc.*, 19, 146, 1917). From results of a series of examinations under the microscope the author concludes that a marked difference in physical condition may be brought about by varations in treatment of a given frit, and that under commercial conditions such variations exist. If the enamel is rather lightly burned, the major portion seems to fuse to a matrix of glass containing fine bubbles and particles of unfused materials in suspension. No doubt this unfused material consists essentially of clay or other of the more refractory mill additions. If the enamel is burned to about the normal degree, this unfused material practically disappears and the minute bubbles seem to run together, forming larger units and leaving greater masses of glassy material between. On further burning, the bubbles continue to combine until they become of sufficient size to produce surface pitting which can be detected by the naked eye. There are apparently chemical reactions which take place, resulting in the formation of gases giving rise to this increasing porosity. Some microphotographs are reproduced.

AMERICAN CLAYS FOR FLOATING ENAMELS.—J. B. Shaw (*Trans. Amer. Cer. Soc.*, 19, 339, 1917). In preparing enamels for use, the frit is ground wet with from 5 to 10 per cent. of its weight of clay, the clay mostly used for this purpose in the States being the German Valender clay. Some flocculating agent is always added, generally magnesium sulphate in white and cover enamels, but in the case of ground coat enamels borax is almost universally used. Nearly all other salts which act as flocculating agents cause rusting of the steel in drying the enamel and thus give trouble. Sodium carbonate can be used, but this is less effective than borax. The proportions found best were 0·5 per cent. of the weight of the frit in the case of magnesium sulphate, 3 per cent. for borax. Valender clay is a very clean and very plastic ball clay and gives excellent results when used in enamels, preventing settling of the frit in the dipping tubs and making the enamel easily tempered to proper consistency for dipping.

As a result of the investigation it was found that Tennessee ball clay or Florida clay were good for floating enamels and glazes. The relation between the viscosity and the specific gravity of enamels gives a value which represents the consistency. A simple and effective form of viscosimeter is described.

CONTROL OF FUSIBILITY IN FRITTED GLAZES.—H. F. Staley and R. J. Riley (*Trans. Amer. Cer. Soc.*, 19, 642, 1917). An account of an investigation conducted to see whether a system of empirical physical factors, for use in substituting one chemical for another while keeping the fusibility of the composition unchanged, would give satisfactory results in fritted glazes for claywares when fired at cones 05, 02, 1 and 3.

Factors for obtaining melted weights from raw weights are as follows, felspar, flint, tin oxide, zinc oxide, and litharge being calculated as not losing any weight in melting:

Red lead × ·974	= PbO	Borax × ·53	= $Na_2O.2B_2O_3$
White lead × ·863	= PbO	Borax × ·16	= Na_2O
Barium carbonate × ·78	= BaO	Borax × ·37	= B_2O_3
Soda ash × ·58	= Na_2O	Pearl ash (calcined) × ·68	= K_2O
Sodium nitrate × ·365	= Na_2O	Potassium nitrate × ·466	= K_2O
Magnesium carbonate × ·48	= MgO	Whiting × ·56	= CaO
Boric acid × ·548	= B_2O_3		

Factors for obtaining raw weights from melted weights are as follows, the raw and melted weights being assumed to be the same for felspar, etc., as above:

PbO × 1·023	= Red lead
PbO × 1·158	= White lead
BaO × 1·287	= $BaCO_3$
Na_2O × 1·724	= Na_2CO_3 (soda ash)
Na_2O × 2·74	= $NaNO_3$
Na_2O (from Borax) × 6·25	= Borax
B_2O_3 (from Borax) × 2·7	= Borax
$Na_2O.2B_2O_3$ (from borax) × 1·9	= Borax
B_2O_3 × 1·77	= Boric acid
K_2O × 1·47	= Pearl ash
K_2O × 2·15	= Potassium nitrate
CaO × 1·79	= Whiting
MgO × 2·09	= $MgCO_3$

The authors conclude that it is possible to develop a table of the amounts of the common fluxes and refractories having equal effect on fusibility of fritted glazes. For fairly large variations equal melted weights of K_2O, Na_2O, CaO, MgO, ZnO, PbO, and B_2O_3 have about the same effect on fusibility, but the amounts of flint and felspar having equal hardening effect must be determined experimentally. In this investigation 2 lb. of flint was found to have slightly more effect in increasing refractoriness than 3 lb. of felspar. The extent to which this system of substitution can be used without affecting texture of glazes must be ascertained by experiment. As compared with high flint enamels, high felspar enamels were more opaque, of higher lustre, and had longer heat ranges. High lime gave enamels that were decidedly pink.

RAW LEAD GLAZES.—F. A. Morgan (*Trans. Amer. Cer. Soc.*, 19, 442, 1917). A study of the chemical and physical properties of three compounds of lead and their use in raw lead glazes. Attention is called to the fact that litharge (yellow oxide of lead) has been satisfactory for glass, enamels, and frits, and it has long been used by yellow ware manufacturers.

The authors concluded that litharge and red lead are equal in purity to white lead, that though the fumed oxides have a higher specific gravity they have greatly superior suspension properties due to their greater fineness, that in substituting these oxides for white lead, an adjustment is necessary in the viscosity of the glaze, that in the unfired condition the oxide glazes have a much harder surface, hence they do not dust so badly, that the oxides effect a saving due to their greater content of lead oxide, that in the physical behaviour of these oxides there is nothing to prevent their substitution for white lead, and that the resulting glaze will be the same, provided equivalents of PbO are present, whether the lead be added in the form of litharge, red lead or white lead.

CRAWLING OF MATT GLAZES.—C. F. Binns and M. E. Saunders (*Trans. Amer. Cer. Soc.*, 19, 597, 1917). The results of tests indicate, as the most important general factor in affecting the tendency to crawl, the burning of the body, the factor of next importance being the grinding of the glaze;

additional grinding (beyond half-an-hour) increased the tendency to crawl, caused the glaze to flow during burning and tended to produce blisters. The use of gum-tragacanth mucilage helped a good deal, especially when all the clay content was calcined.

Some interesting points were alluded to in the discussion following the paper.

EFFECT OF BODY POROSITY AND GLAZE MOISTURE IN MATT GLAZES.—F. S. Hunt (*Trans. Amer. Cer. Soc.*, 19, 428, 1917). An investigation of the effect on the matt texture of different porosities of tiles and of the moisture content of the glaze.

It was concluded that the weight of glaze per unit area is the determining factor in the control of matt texture. The limits observed for the three representative raw lead matt glazes investigated were that desirable effects could be obtained with a weight of from 0·10 to 0·135 grams per sq. cm. No effect of the porosity of the body and moisture content of the glaze, other than in the control of the weight of glaze per unit area, could be observed.

COST OF RAW LEAD GLAZES.—H. F. Staley and L. C. Hewitt (*Trans. Amer. Cer. Soc.*, 19, 659, 1917). An investigation to discover the areas of good bright and matt glazes, and to calculate the cost of material for such raw lead glazes. The results are given mostly in tables and are expected to help users of raw lead glazes to find the glaze that will give them the minimum loss of ware with the least cost for glaze material

INVESTIGATION OF WILLEMITE-TEPHROITE-SODA-GLASS.—H. C. Arnold (*Trans. Amer. Cer. Soc.*, 19, 674, 1917). A study of glaze crystallization from a mineralogical standpoint, by investigating the ternary system consisting of soda glass, willemite (zinc orthosilicate), and tephroite (manganese orthosilicate). The soda glass had a composition represented by $Na_2O.2SiO_2$, and all three were prepared synthetically. The proportions used and the results obtained are shown by means of triangular diagrams and curves.

The author indicates the following conclusions: Commercially desirable crystals of willemite develop best when there is about 50 per cent. willemite and 50 per cent. glass in which the crystals can grow. More willemite produces chiefly small undeveloped crystals. Three compounds of manganese are produced, hausmannite (Mn_3O_4), rhodonite (manganese metasilicate), and tephroite. Hausmannite is the first to be formed, and seems to be the most insoluble in the silicate melt. When the mass is free to attack siliceous material, rhodonite is usually formed instead of tephroite. Long heating at a temperature of moderate viscosity greatly increases the development of hausmannite. There seems to be a limited isomorphous crystallization along the willemite-tephroite line.

STUDY OF THREE-COMPONENT NORMATIVE SYSTEMS IN RAW LEAD GLAZES.—W. G. Whitford (*Trans. Amer. Cer. Soc.*, 19, 312, 1917). The "norm" of a rock is its standard mineral constitution, as constituted on the assumption that the salts in solution in rock magmas may be considered as having the composition of those minerals which separate and crystallize when the magmas solidify. The method has been used in several previous glaze investigations. In the present case, care was taken to choose normative end members which were quite simple in composition, and between which there would probably be no chemical reaction and no compounds formed. Three series of glazes were examined: (1) Anorthite series. (2) Wollastonite series. (3) Zinc silicate series.

In the anorthite series the normative end members were orthoclase or potash felspar, $K_2O.Al_2O_3.6SiO_2$, anorthite $CaO.Al_2O_3.2SiO_2$ (made from whiting and North Carolina kaolin), and lead metasilicate, $PbO.SiO_2$, made from white lead and flint. The series consisted of 55 mixtures, made up from suitable proportions of 3 mixtures which were prepared in quantity.

In the wollastonite series the norms chosen as end members were orthoclase or potash felspar, wollastonite, $CaO.SiO_2$ (made from whiting and flint), and lead metasilicate. The series again consisted of 55 members.

In the zinc silicate series the normative end members were orthoclase or potash felspar, zinc metasilicate, $ZnO.SiO_2$ (made from zinc oxide and flint) and lead metasilicate. This series also comprised 55 members.

The glazes were applied to white wall-tiles and fired in laboratory muffle kilns at cones 05, 02, 1 and 3, the time of burning varying from 12 to 16 hours.

The following general conclusions were reached: (1) When the normative end members are properly chosen, the normative system of glaze calculation and blending gives series of glazes whose physical properties vary in regular and easily explicable manner. (2) Glazes made from blends of anorthite norm with lead metasilicate norm and orthoclase gave more refractory glazes than those in the other two series, and a large proportion of matt and semi-matt glazes. Mattness was a function of temperature and composition, a certain minimum content of anorthite norm being essential at each heat treatment. The line dividing dull finish from bright glazes was fixed by this minimum anorthite content and bore no relation to oxygen ratios. (3) Glazes made from blends of wollastonite norm with lead metasilicate norm and orthoclase were mostly bright. The few matts developed were of silky texture and had quite low alumina contents. The line dividing dull finish from bright glazes was fixed at each temperature by a certain minimum wollastonite norm content. (4) Glazes made from blends of zinc metasilicate norm with lead metasilicate norm and orthoclase were mostly bright glazes and stoneware enamels. A few matts and crystalline glazes were produced. The matts in this series seem to be truly crystalline.

THE PRACTICAL APPLICATION OF BRISTOL GLAZES COMPOUNDED ON THE EUTECTIC BASIS.—A. S. Watts (*Trans. Amer. Cer. Soc.*, 19, 301, 1917). Three glazes, selected from the eutectic area referred to in the Bristol glaze study reported by the author in the last volume, were tested commercially. They were compounded as follows:

	Felspar	Whiting	Zinc oxide	China clay	Ball clay	Flint
A ...	60·87	6·25	7·76	7.06	7·06	11·00
B ...	57·07	5·86	10·69	8·15	8·15	10·08
C ...	50·10	9·01	9·73	9·07	9·07	13·02

These glazes were all applied at 22 ounces to the pint, and proved practical over a range from cone 3 to cone 14. Whenever properly ground a smooth bright coat has resulted. A wide variety of clays has been glazed with apparently equal success. Even at cone 10 the opacity of all three is sufficient to satisfactorily mask the colour of a buff clay. At cones 12 and 14 the glazes were used on electrical porcelain and showed almost as much opacity as at cone 10. At cones 3, 4 and 5 these glazes all produce fine smooth enamels, suitable for cooking ware, etc.

No evidence of crazing has been noticed, nor any tendency to crawl when applied at less than 23 ounces to the pint. These glazes will not heal over if the surface is broken, and loose dust on the surface of the ware causes pinholing.

RELATION OF FRITS AND MIXTURES TO DEFECTS IN EARTHENWARE GLAZES.—H. Harkort (*Ker. Rund.*, 23, 273, 285, 297, 317, 1915). Taken from *Zeits. f. angew. Chemie.* The author's conclusions are summarized thus:

For glazes of low acidity the subdivision into frit and mixture is connected with a series of well known faults, like streaky cloudiness, matt coatings, blinding of glazed edges and pinholes, the nature and possibility of removal of which were hitherto more or less unexplained. These connections, and the effect of the total composition of the glazes and the manner of firing were investigated.

With normal earthenware glazes for glost firing at cones 01—6, like those used for the better earthenware, the defect is generally caused by too high a content of lime. That should not in glazes of more than 2·5 equivalents silica exceed 0·4 equivalents and should be lowered as the degree of acidity is reduced.

It is to be observed that a more difficult taking up of lime through the glaze into the body results, as lime is not included in the frit.

Blinding in the vicinity of porous parts arises through evaporation of boron trioxide from the glaze, and this occurs the more the glaze is exposed to the action of sulphuric acid from the fire gases Such action in glazes with less than 2·5 SiO_2 and 0·4—0·5 CaO causes matt separations, complete wasting away of the glaze, and bursting of large blisters, whilst with increasing silica and falling lime content this danger disappears and only a pinholed glaze surface arises.

The presence of $CaCO_3$ acts as a protection against the attack of H_2SO_4 on the glaze and therefore against evaporation of boric acid.

Lead oxide in the mill mixture is extraordinarily effective for smoothly taking up lime even from the mill mixture in glazes, which by supply of the lead oxide through the frit and with otherwise equal content of this oxide are only in a position to do so at substantially higher temperature.

Lead oxide in the mill mixture exerts no influence on the evaporation of boric acid. These view-points provide correct lines:

1. For reducing the lead oxide content and thereby cheapening the glazes and increasing the content in cheap lime.

2. Accordingly for the employment of leadless glazes, whose certainty of operation is limited by the appearance of the defects described.

3. For the fritting in of such portions of lead oxide as were introduced in existing glazes in the mill mixture.

4. For prevention of losses in the very expensive boric acid.

5. For decreasing pinholing of the surface of glazes.

6. For avoidance of defects due to use of coal containing sulphur, and for adaptation to altered firing conditions.

7. For production of satisfactory coloured glazes, the character of which is changed by the often considerable addition of metallic oxides or lime-containing colours strongly opposed to that of the unmixed glaze.

TURQUOISE BLUE COPPER GLAZES.—H. Hecht (*Ker. Rund.*, 23, 133, 1915). Refers to a paper by A. Granger on a similar subject, the results given in which the author claims to have anticipated in 1895 (*Tonind. Ztg.*, p. 454).

CRYSTAL GLAZES.—C. Kabus (*Ker. Rund.*, 23, 139, 165, 178, 183, 1915). A general survey of the field of crystalline glazes, with special reference to certain special compositions, mostly based on stoneware glazes and suitable for firing at cone 8—10 on soft porcelain.

ENAMELLING CAST-IRON VESSELS.—H. Vogel (*Ker. Rund.*, 23, 109, 1915). All cast-iron is not suitable for enamelling; the enamel sticks on hard white cast-iron better than on the softer grey. It is desirable therefore to obtain a thin layer of white iron on the inner surface, on which the enamel is to be laid. This is attained by keeping the moulding sand for the inside, the core, as cool as possible, and wetter than the sand for the outside. Advantage may also be taken of the fact that by melting iron containing sulphur there is produced a hard iron resembling the white; this is done by dusting the surface of the core with sulphur powder. Dusting of the mould with graphite is to be avoided in all circumstances, as some of the graphite would remain adhering to the iron even after careful cleaning.

Irregular thickness of the iron is often a cause of chipping off of enamel. Even the shape of the vessel often tends to have a similar effect.

Of great importance is cleaning of the vessel before enamelling.

The ground enamel must be distinctly harder than the covering enamel, for which a content of 70 to 75 per cent. of silica is necessary. Care should be taken not to frit it too strongly, and the grinding also needs attention. It is important that the expansion coefficient of the ground enamel should agree with that of the iron. For it to adhere well to the iron at least a bright red heat (to 950° C.) is necessary.

For durability a single thin coat is advantageous, which according to experience can be produced by addition of 10 per cent. tin oxide to an otherwise good covering flux.

ENAMEL AND ITS USE IN THE CHEMICAL INDUSTRY.—J. Schæfer (*Ker. Rund.*, 23, 280, 287, 293, 1915). A general discussion of enamels on metals, more especially on sheet iron and cast-iron.

NEW OPACIFYING MATERIAL FOR WHITE IRON ENAMEL.—(*Ker. Rund.*, 23, 221, 1915). Tscheuschner (1885) and Wilkens-Schumacher (1884) credited opacifying properties to sodium aluminate and alumina. But a substance giving white opacity to glass fluxes is by no means always employable to give white opacity to enamels. It must to a certain extent enter into reaction with the covering enamel in order to give smooth surface. Trials with sodium aluminate and alumina gave no satisfactory results, and the same may be said of magnesia.

It has now been proved that mixtures of magnesia and alumina, or of zinc oxide and alumina, give good opacification when heated sufficiently to form spinels or solid solutions of spinel with magnesite or alumina. This action is strengthened by adding tin oxide, zirconia, titanic acid, silica or other white refractory substance or suitable mixture of the substances named, and the mixture ignited. Addition of 10 per cent. to the alumina and magnesia, or alumina and zinc oxide, that is, the use of 5 per cent. of opacifying material containing ½ per cent. on the enamel mass, suffices to produce a considerably stronger opacifying action than the ignited pure mixture. Calcium spinel and barium spinel have no such effect.

The process was patented by E. Heilmann (D.R.P. No. 285,822).

NON-CRAZING GLAZES AND POROUS BISCUIT.—C. Tostmann (*Ker. Rund.*, 23, 83, 1915). Reference is first made to A. Berge's assertion (in his "Keramisches Praktikum") that on very porous biscuit all glazes will craze sooner or later owing to the very different expansion coefficients of the glaze and the body, and that the loose texture of the body should be made denser, so far as is permissible, which can be done most simply and advantageously by addition of lime.

It is correct that it is easier to obtain products with a non-crazing glaze on a quite dense body than with a porous body. But if a good earthenware glaze be fired on a dense-burned porcelain body it will certainly show crazing. This is quite explicable from the fact that the expansion coefficient of earthenware is about three times that of porcelain. Increase of the felspar content of the earthenware would also result in crazing with the same glaze, but increase in quartz content of the mass would remove crazing in the glaze.

It is correct that by increasing the lime content of an earthenware mass the crazing of the glaze can be remedied, but it is erroneous to assume that the biscuit is made denser thereby, nor is this desirable, for with lime masses the sintering point and the melting point lie very close to one another. Actually the greater porosity caused by the expelled CO_2 is not appreciably reduced, and all masses containing much lime are much more porous than felspar masses, and non-crazing glazes can be melted on them just as easily and with as much certainty as is possible with felspathic earthenware—many ceramists contend that it is even easier.

The author maintains that generally crazing may be either a glaze fault or a body fault (not exclusively the latter), but arises through disagreement of glaze and body. There are glazes for which a body can scarcely be found, and there are also bodies on which almost every glaze crazes. Such bodies can be very porous or tolerably dense.

The author has seen tolerably dense hard earthenware which only crazed after 13 years, and very porous lime earthenware which has been in use 23 years without showing a single craze.

NITRE-SUBSTITUTION IN THE ENAMEL INDUSTRY.—F. Kraze (*Ker. Rund.*, 23, 5, 1915). A discussion of possible substitutes for potassium and sodium nitrates, and their mode of action. Reference is made to atmospheric

oxygen, water vapour (introduced by stirring the fluid glass by means of a fresh moist stick of wood, or by putting a potato at the bottom of the molten glass), and barium peroxide, the last-named being rather expensive, but producing no discolouration, and giving off its oxygen at 700—800°.

Reference is also made to the process long used in ceramics for purification of tin-white enamel glazes by melting with 10 per cent. of common salt, volatile chlorides being formed, especially iron chloride. The decoloration of the glaze results therefore through an actual removal of iron. For removal of the remaining undecomposed salt the glaze must be thoroughly washed until the wash water gives no precipitate with silver nitrate solution. In iron enamelling practice the melting with common salt is not used yet. The author's experiences therewith were gained from laboratory trials, but promise good results for large scale operations.

NITRE-SUBSTITUTION IN THE ENAMEL INDUSTRY.—C. Tostmann (*Ker. Rund.*, 23, 15, 1915). Brief reference is made to manganese, calcium and barium nitrates, and barium peroxide, as recommended in previous articles by Eyer, Grünwald, and Kraze (above). Mention is also made of chlorates, persulphates and perborates. Most of them are considered impracticable on account of expense or difficulty of obtaining them. Persulphates are objectionable because of leaving sulphates in the enamel. Also in nearly all cases a relatively large addition is necessary.

The author agrees with Kraze that, at least in tank meltings, nitre can be very well dispensed with, and also with most of his other conclusions.

ENAMEL POWDER TECHNOLOGY.—F. Kraze (*Berichte der Technisc wissenschaftlichen Abteilung des Verbandes keramischer Gewerke in Deutschlan* 2, 65, 1914). The ground dry enamel, fine as dust, was applied to the red-hot iron vessel either by dipping the latter into the powder and turning it about, or by dusting the powder on to it. In both cases the enamel must be very easily fusible, and it must become soft and adhere at the first contact with the red-hot iron, especially powder applied by dusting. Enamel powder can thus be thoroughly suited for horizontal and little inclined surfaces, whilst for steep surfaces of the same vessel it is too hard. The enamel powder is caused to turn smooth quickly by the heat of the iron so that a burning in the enamel muffle is unnecessary, and even injurious on account of the danger of overheating in the case of lead enamels. But leadless powders, and particularly those which are acid-proof, require this subsequent burning. Lead enamels are used for various cast-iron articles, but are no longer employed for vessels intended for eating, drinking, or cooking. In using lead enamel the dipping powder process is decidedly to be preferred to the dusting powder process on account of the prevention of flying about of enamel dust, and also because in the dipping no enamel gets lost. Historically the wet coating follows powdering. It was rendered possible by the introduction of clay, which is added in the mill to the fritted enamel for the most part granulated in water. It makes the enamel more refractory, but confers on it also a greater power of chemical resistance than powder enamel possessed in the first epoch of enamel technology. Under this advance the appearance of the manufactured goods must suffer loss, for powder enamelled vessels receive a mirror-smooth surface, which seems as if polished and far surpasses vessels enamelled by wet coating. With wet coating the unburned enamel clay, in consequence of its contraction in drying, clings to the very fine inequalities of the iron surface, especially the cast-iron, so that they remain still visible under the burned enamel.

The constitution of these enamels is illustrated by the following molecular formulæ:

$$\text{I.}\quad \left.\begin{array}{l} 0{\cdot}20\,PbO,\ 0{\cdot}29\,ZnO, \\ 0{\cdot}12\,BaO,\ 0{\cdot}07\,CaO, \\ 0{\cdot}20\,Na_2O,\ 0{\cdot}12\,K_2O, \end{array}\right\} 0{\cdot}12\,Al_2O_3 \qquad 0{\cdot}80\,SiO_2.0{\cdot}16\,B_2O_3$$

$$\text{II.}\quad \left.\begin{array}{l} 0{\cdot}20—0{\cdot}00\,ZnO \\ 0{\cdot}74—0{\cdot}70\,Na_2O \\ 0{\cdot}06—0{\cdot}11\,K_2O \\ 0{\cdot}00—0{\cdot}19\,CaO \end{array}\right\} \left.\begin{array}{l} 0{\cdot}12—0{\cdot}15\,Al_2O_3 \\ 0{\cdot}00—0{\cdot}13\,Sb_2O_3 \end{array}\right\} \left\{\begin{array}{l} 0{\cdot}77—0{\cdot}64\,SiO_2 \\ 1{\cdot}14—0{\cdot}68\,B_2O_3 \\ 0{\cdot}043—0{\cdot}00\,P_2O_5 \\ 0{\cdot}34—0{\cdot}00\,SnO_2 \\ 0{\cdot}60—0{\cdot}86\,F \end{array}\right.$$

I is an actual lead enamel powder for dipping.

II gives the limiting values of a series of practical leadless powder enamels for dusting.

These powders are suitable for cast-iron and cannot be melted on faultlessly, without a ground. While formerly the ground also was powdered, to-day this is laid on moist and firmly burned in the most suitable way so that it may still remain as far as practicable new. The molecular proportions of formula II to the left furnish a very easily fusible powder, and to the right a powder which will run on steep surfaces, whose viscidity on hot walls, inclined below 45°, is still satisfactory.

For powder enamels it is first necessary (whether acid-proof or not) for the raw mixture to be really better mixed up than for ordinary enamels, and especially so for acid-proof enamels, and at the same time the material should be finely ground. For suitably mixing and grinding, the edge-runner is recommended. The enamel should be protected from contamination with iron particles.

The well mixed mass is next fritted. If this be done in a cracked crucible, under reducing conditions, a powder enamel with tin oxide inclines specially to a blue grey to dark blue colour, which recalls cobalt. Zirconia enamels never became grey under such conditions.

With enamels laid on moist the opacifying oxides are not melted in the frit kiln, but are first added at the mill; but this is not permissible for powder enamels, for in dusting through the sieve a sorting-out of portions of different specific gravity is likely to take place. Zirconia has given trouble in this way, but a very fine leather brown cloudy effect has thus been obtained. Otherwise this enamel with earthy zirconia (which latter cost about a shilling a pound in 1914) was extraordinarily resistant towards very abrupt changes of temperature and towards percussion. Zirconia enamel, besides having good covering power, is also tolerably acid-proof. The resistance of zirconia to reducing influences is extremely pleasing. Powder enamels with zirconia can be applied direct on iron, without introducing a ground enamel. In powders rich in lead, zirconia seems to tend still more strongly to clouding than in leadless ones.

Tin oxide up to 10 per cent., fritted into the enamel, produced in lime soda borosilicates no satisfactory clouding, and up to 3 per cent. there is no clouding effect at all in such powder enamels. Fluorine in addition to tin oxide greatly strengthens the cloudiness, though alone it has only slight effect. This clouding effect was yet considerably strengthened by applying the powder on brightly red-hot iron and finally burning smooth in the enamel muffle. In quite analogous manner the presence of fluorine causes cloudiness of otherwise clear dissolving antimony oxide, tricalcium phosphate, barium phosphate, zirconium phosphate, and zirconia. These facts indicate how enamels may be made cheaper. The author has introduced barium and zirconium phosphates into enamels by using barium carbonate and zirconia respectively with the necessary quantity of sodium phosphate. Such barium powder enamels are distinguished by a considerably brighter lustre than those of analogous composition made with calcium phosphate. It further appears that clouding of zirconia is strengthened, besides the combination with fluorine, by using it as zirconium phosphate.

In enamels containing lime, cloudiness is produced by introducing tungstic acid. It is also pretty well known that clouded enamels can be produced by the mere introduction of sufficient cryolite, fluorspar, or sodium silico-fluoride. From his experiences in the production of fluoride powder enamels the author has come to the conclusion that the cloudiness depends chiefly on the presence of free silicon fluoride besides aluminium fluoride, but that the enamel only after complete extraction of the silicon fluoride or only in the presence of aluminium fluoride can be acid-proof and at the same time clouded, assuming that the enamel contains no other clouding compounds, or that it is clear like glass when it contains no fluorine. Enamel after running was found, cooled with a bluish tinge, the more glassy (or less clouded) it was, the longer the melting process, assisted by intimate mixing, or the hotter the melting process.

That depends on the continuous and complete extraction of the silicon fluoride. The reaction is perceived through the pungent odour of this gas, and when the smell does not arise in the running of the enamel it is certain that only feeble cloudiness will appear on cooling. The completion of the extraction of gas is also recognized by the formation of bubbles in the enamel flow no longer taking place. The feebly opaque enamel freed from silicon fluoride can be brought to a good white covering even over a not too dark ground enamel.

The ground enamel for cast-iron needs neither cobalt nor nickel, and therefore can be produced light. If the enamel after grinding be stencilled and burned in the muffle, the effect is unsatisfactory. But if the vessel cooled to a dark heat be moved back into the muffle and then hurriedly taken out again after a few seconds, a distinct strengthening of the clouding can be perceived with fluoride enamels melted in the way before-mentioned, which can be increased to a high degree according to the thickness of powder laid on and by more frequent repetitions of the operation. Such enamels, free from any other clouding materials than fluoride, were in general the most acid-proof. The author ascribes the effect to the separation of aluminium fluoride. A flat cake trial of the melted enamel before complete extraction of the silicon fluoride shows a strong white clouding. If the trial be now laid in dilute acid (a 0·5 to 1 per cent. of hydrochloric acid suits best), in a few seconds there appears only on the flat surface of the trial which lay upwards in cooling a striped marking, consisting of matt-etched streaks, which alternate with unattacked clear parts. The matt parts of the enamel are those from which the silicon fluoride has burst through. By contact with the diluted acid fluosilicic acid was formed, which needed alkali of the enamel for formation of potassium fluosilicate. All silicon fluoride had already escaped from the clear parts in the melting and stirring. The streaky structure is itself a result of the stirring. When a trial remains for the first time clear in the acid, the tapping of the whole melt should follow as quickly as possible, in order that the enamel in moderately thick layer on the iron can still cover strongly white. If the enamel be superfused it finally comes clear as glass, and the attacks described take place no longer. Then at last the stable aluminium fluoride has been decomposed with discharge of the fluorine. Aluminium could now dissolve clear in the enamel as alumina.

Even with premature tapping the enamel can still come out fire-proof, because the rest of the silicon fluoride escapes later in the melting of the powder. This extraction of gas is hastened by increase of fineness and can be completed by carrying the powdered products into the enamel muffle and keeping them there for prolonged periods.

On dark ground overheated (and so insufficiently clouded), acid-proof powders can scarcely be made to form thoroughly satisfactory covering. Where the covering powder is not white enough, it must be strengthened by the introduction of a small amount of tin oxide, antimony oxide, zirconia, titanic acid or the phosphates mentioned. If more than a small quantity be used the acid-proof quality suffers, except in the case of the very acid-proof zirconia.

Melting in crucibles does not give such satisfactory results as when larger quantities of enamel can be melted, because the melted enamel cannot be kept well stirred, and it is impossible to get acid-proof fluoride enamels by a single melting in a crucible. Where crucibles must be used the melting must be repeated until satisfactory trials are obtained, and the crucibles should not be closed, or the gases, especially silicon fluoride, cannot escape.

The best shape and arrangement of the melting bath is discussed at some length. An oval shape is recommended with one working aperture, which should lie in front of the head of the oval. With rectangular baths two opposite apertures should be provided for the introduction of stirring rakes.

For production of acid-proof powder gas-firing is to be preferred, but reductions must be avoided. The easily reducible oxides of tin and antimony particularly require an oxidizing fusion. If the flame be smoky or contain carbon monoxide, fluoride enamel clouded with assistance of oxide of tin or antimony shows in spite of otherwise snow-white appearance and splendid

lustre a softly iridescent surface, especially with longer contact of the enamelled vessel with diluted acid. It retains its high lustre even after a whole day in dilute acid, and concentrated acid has less decomposing action than dilute acid. These interference colours doubtless arise from very minute quantities of reduced tin and antimony. The appearance is removed by increasing the nitre content of the mixture. The complete prevention of carbon monoxide in gas-firing is feasible with difficulty, but the use of compressed air is of advantage.

For grinding acid-proof powder enamel special care is necessary to avoid the introduction of impurities.

The ground material should pass through a sieve of 900 meshes to the square cm., and should be finer than this for sloping surfaces.

WHITE ENAMELLING.—*Verein Chem. Fabrik Landau*, Swed. Pat. 41,858, Jan. 10th, 1917. An anhydrous zirconium compound poor in alkali is used as clouding agent, and is treated with metallic salts the oxides of which also produce clouding effects.

VII.—COLOURS & DECORATIVE PROCESSES.

A MACHINE FOR DIRECT PRINTING ON POTTERY.—W. Sharratt (Trans., 16, 16, 1917). An appliance in which rubber is used for receiving and transmitting the designs.

STUDY IN CHROME-TIN PINK.—E. W. T. Mayer (Trans., 17, 104, 1918). A brief account of trials, some results being shown by means of a coloured triangular diagram.

EFFECT OF MAGNESIAN GLAZES ON UNDERGLAZE COLOURS.—C. P. Shah (Trans., 17, 106, 1918). A report of the results of trials made with certain glazes and colours of specified composition.

CHROME-TIN COLOURS AT CONE 9.—R. H. Minton (*Trans. Amer. Cer. Soc.*, 19, 378, 1917). Trials were made to produce a stain that would develop a red when used in a slip under a transparent glaze at cone 9. The best slip was obtained by using a stain made from 46½ parts by weight of $CaCO_3$, 10 of $PbCrO_4$, 12⅜ of SiO_2, and 31⅛ of SnO_2, the unstained slip being made from 20 of Maine felspar, 35 of flint,, 38 of china clay, 5 of Florida kaolin, and 2 of whiting. It was concluded that to develop the pink colour in the underslip the glaze must contain tin oxide, and that the composition of the glaze is more important than the composition of the stain. A long firing (144 hours in large kiln) weakened the colours considerably, but the glaze and stained slip mentioned were again the best. Refiring in the large kiln after first firing in the trial kiln (39 hours) weakened the colours more. In the long burning the colours are permanently lost, and cannot be restored by succeeding oxidizing fires.

In connection with the stain it was concluded from further trials that $SrCrO_4$ and $BaCrO_4$ produce stronger colours than $PbCrO_4$, $ZnCrO_4$, K_2CrO_4, $K_2Cr_2O_7$, or Cr_2O_3, the last named being the next best, while $ZnCrO_4$ produces a strong colour. $CaSO_4$ is not so good as either $CaCO_3$ or CaF_2. In glazes $CaCO_3$ and CaF_2 were equally good, and either better than $CaSO_4$. It was also concluded that the glaze must contain SnO_2 to develop the colour, 0·10 to 0·20 eq. of SnO_2 being best (but 0·30 eq. too much). Here too the composition of the glaze seemed to be more important than the composition of the stain.

Further trials were made with glazes to which 10 per cent. of stain was added. The conclusions arrived at regarding these coloured glazes (fired to cone 9) were that $SrCrO_4$ and $BaCrO_3$ are better sources of Cr_2O_3 than $PbCrO_4$, $K_2Cr_2O_7$, K_2CrO_4, or Cr_2O_3, and that Cr_2O_3 is much better than the other three, that CaF_2 produces stronger colours than $CaCO_3$, and that stain containing silica and $PbCrO_4$ is stronger than stain with $K_2Cr_2O_7$ and no silica.

Trials with a glaze with 10 per cent. of stain added, and fired at cone 02, showed that $BaCrO_4$ develops the strongest shades, with brownish tints, and

CaF_2 seems to be the best source of CaO, while $K_3Cr_2O_7$ is the best source of Cr_2O_3 for clear red.

Unwashed stains are much the best for strong colours. Washing greatly influences the shade, and the source of the Cr_2O_3 has marked influence upon the final colour developed in the glaze.

OVERGLAZE COLOURS AT CONE 6—7.—H. Wilson (*Trans. Amer. Cer. Soc.*, 19, 653, 1917).—A method devised for yellow and white polychroming on terra-cotta. A white glaze was sprayed in the regular way, and yellow colouring agents were applied in an overglaze manner where necessary. The separate painting of two coloured glazes with a hair brush would be too costly. After spraying and when dry, the pieces are transferred to a revolving table, and the yellow overglaze applied with a fine air brush, care being taken to coat the background to an even colour and to avoid wetting the raised ornament. Pink, rose and tan colours were also obtained, as well as violet, browns, green, and numerous other tints may be developed for this single fire overglaze work. Possibly they might give more brilliant colours over lower heat glazes at lower temperatures. Akin to this adding of colour to the piece is the painting of soluble metallic salts into parts of an ornamental design. Spraying soluble salts gives blurred outlines to a design. Pleasing shading and blending effects with the spray of one or more soluble salts are easily obtained.

This single fire method for developing both glaze and overglaze is used in producing the old ivory finishes in pottery ware.

CERAMIC SGRAFFITO.—Leon V. Solon (*Architectural Record*, 42, 141, 1917). Reference is made to the art of the cartographers of olden times, whose maps and charts—for want of more accurate information—were embellished with more or less fanciful figures or groups of figures, etc., intended to convey some notion of the general features of the country or district. With increasing facilities for measurement and for travel the employment of the decorative features became more and more restricted until they were finally abandoned altogether in maps.

The importance of research as an aid to imagination is strongly insisted upon. It is suggested that certain spaces in buildings—as the great entrance halls of national or civic institutions, and certain parts of the larger country houses—lend themselves well to a style of mural decoration which has direct reference to its surroundings, an expression extremely hard to convey by means of historic ornament, whilst the conventional type of mural painting would be inappropriate. The choice of a new alliance among the architectural crafts for this must be guided by the following considerations: that delicacy and precision of detail shall be practicable in the new material; that simple polychrome effects of a permanent nature be available; that those qualities associated with structural materials be possessed which will permit the work to become an integral part of the building. Of structural materials, potters' clay seems to have the best qualifications to meet the technical and decorative requirements, and of processes and methods ceramic sgraffito offers the greatest facility for rendering delicacy of line in two colours.

The thin coat of light clay covering the red clay slabs is worked on when still moist, and is an excellent substance in which to engrave the outline or shading with a pointed tool. The line is drawn, cutting through the white clay, showing the reddish ground, the white clay being scratched anywhere dark masses are needed. The thickness of the white layer is such that effects of a delicacy comparable to the original can be attained with the utmost freedom. This coating can be stained with metallic oxides to an infinite number of tints. The additional polychrome resources and textures realizable by glazing are very extensive.

The manipulation of the process demands only good freehand draughtsmanship. By way of examples, designs are given for mural decoration in the entrance hall of a college, and for map of a seaside estate.

DECORATING, WITH COLOURS, SOLID OR HOLLOW CLAY OR CEMENT PRODUCTS.—G. Blatt, Ger. Pat. 292,709, June 24th, 1914. The

article, placed in an exhausted vessel, is impregnated with the colouring solution, rising slowly from below upwards until the article is covered. Designs can be made with solution of cellulose acetate, and the coloured articles may be impregnated with this solution. If only partial decoration is intended, a float may be used to stop the rise of the liquid. To produce a sharp bounding line between the coloured and uncoloured portions, the solution is allowed to rise to the height required, the vacuum is then interrupted, and the liquid is run off at once. For producing a gradation of the colouring, the solution is allowed to remain for some time *in vacuo*, colour being thus drawn up into the exposed portion. Cellulose acetate applications being transparent need not be removed. Impregnation with cellulose acetate after colouring fixes the colour more firmly in the body of the article, and prevents removal by various solvents, besides increasing the brilliancy of the colour. It is claimed that the process is a cheap one.

ORNAMENTING CERAMIC PRODUCTS.—C. A. Kobisch, Ger. Pat. 292,481, Feb. 9th, 1915. Particles of coloured glass or porcelain are forced into the ceramic mass before drying and burning. Engobe or glaze may be added if desired.

METALLIZING SILICEOUS SURFACES.—(*Metal Ind.*, 11, 200, 1917.) A process for coating siliceous surfaces (glass, pottery, etc.) with metal, taken from *La Révue des Produits Chimiques.* The surface—which must not be enamelled or varnished—is treated with silver fluoride solution, and then exposed to a current of coal gas. It is afterwards subjected to the action of a current of carbon disulphide at a temperature of 50° C. Finely divided silver is deposited on the non-conducting surface, and after burnishing this it can be used as the cathode in an electro-plating bath.

VIII.—COSTS, MANAGEMENT, ORGANIZATION COMMERCIAL REPORTS.

UNESTIMATED LOSSES IN POTTERY MANUFACTURE.—A. Leese (Trans., 16, 189, 1917). Presidential address dealing with unnecessary expenses or waste in connection with such matters as boilers, slipmaking, jollying, and moisture in purchased materials.

SCIENTIFIC MANAGEMENT AND ITS APPLICATION TO FIREBRICK WORKS.—C. W. Thomas (Trans., 16, 274, 1917). A general survey of the subject, followed by a brief consideration of particular aspects, including mining and selection of raw materials, methods of making, drying and burning, utilization and direction of labour, costs, etc. Incidentally a special device for measuring shrinkage during firing is described and illustrated.

GENERAL ORGANIZATION OF FIREBRICK WORKS.—G. W. Wight (Trans., 17, 74, 1918). A review of the whole subject arranged under four heads or departments—works or manufacturing department, commercial or sales department, financial and book-keeping department, and secretarial and statistical department.

ASBESTOS.—O. B. Hopkins (*The Mineral Industry*, 25, 62, 1917). A review of the production, imports, etc.

BARIUM AND STRONTIUM.—(*The Mineral Industry*, 25, 77, 1917). A review of the production, imports, etc., of barium and strontium minerals and compounds.

BORAX.—J. W. Beckman (*The Mineral Industry*, 25, 84, 1917). A review of the production, imports, etc., of borax. Reference is also made to priceite (a somewhat impure variety of colmanite from Oregon).

CEMENT.—R. W. Leslie (*The Mineral Industry*, 25, 90, 1917). A review of the production, exports and imports, etc., of Portland and other cements. Brief reference is made to the commercial production of potash from cement dust.

CHROMITE.—S. H. Dolbear (*The Mineral Industry*, 25, 100, 1917). A review of the production, imports, etc. Also a bibliography of recent publications bearing on the subject.

CRYOLITE.—(*The Mineral Industry*, 25, 265, 1917). A very brief review of the production and imports. The world's supply comes entirely from the deposit at Ivigtut in Arauk Fjord, South Greenland, though the mineral is found in small quantities around Pike's Peak (Colorado) and in some other localities.

FELSPAR.—A. S. Watts (*The Mineral Industry*, 25, 266, 1917). A brief review of the production and uses. Reference is made to F. W. Walker, Junr.'s, proposed standard method of classification of ground felspar and flint, and to the deformation eutectics between orthoclase or albite and calcite or magnesite respectively (Kirkpatrick). It is used mostly in the pottery and enamelling industries, but also for making glass, and for chicken grits, soap, and other abrasive properties, etc.

FLUORSPAR.—(*The Mineral Industry*, 25, 269, 1917). A brief review of the production, imports, etc.

FULLER'S EARTH.—E. H. Sellards (*The Mineral Industry*, 25, 271, 1917). A very brief review of the production, imports, and uses. The chief uses now are for bleaching, clarifying, or filtering fats, greases, and oils; it is also used for pigments, for printing wallpapers, and for detecting certain colouring matters in some food products.

GRAPHITE.—B. L. Miller (*The Mineral Industry*, 25, 369, 1917). A review of the production, etc., in the United States and elsewhere. Artificial graphite is also alluded to.

GYPSUM.—F. A. Wilder (*The Mineral Industry*, 25, 381, 1917). A review of the production, etc., in the United States and elsewhere.

MAGNESITE.—S. H. Dolbear (*The Mineral Industry*, 25, 476, 1917). An account of the geology and mode of formation of magnesite and hydromagnesite (see also TRANS., 16, *Abs.*, 34). Also the production, imports, etc.

MICA.—J. V. Lewis (*The Mineral Industry*, 25, 500, 1917). A review of the production, imports, exports, uses, etc. There is also a short bibliography of recent publications. The uses include its employment as a non-conductor in the electrical industries, for glazing stove and furnace doors, for gas-lamp chimneys and shades, and for reproducing discs in phonographs. Ground mica is used as a lubricant, in vulcanized rubber, and as a heat insulator in coverings for steam pipes and boilers, etc.

POTASSIUM SALTS.—J. W. Beckman (*The Mineral Industry*, 25, 602, 1917). A review of foreign sources, and production in the United States (from kelp, cement, alunite, felspar, and from natural deposits), with a bibliography of recent publications.

SODIUM AND SODIUM SALTS.—S. H. Salisbury, Junr. (*The Mineral Industry*, 25, 645, 1917). An account of the nitrate of soda industry, with a review of the theories of its origin. Also soda and salt, with a bibliography of recent publications, mostly articles in American technical periodicals.

TALC AND SOAPSTONE.—F. B. Peck (*The Mineral Industry*, 25, 695, 1917). A short review of the production, imports, etc.

TITANIUM.—L. E. Barton (*The Mineral Industry*, 25, 716, 1917). A short account of the technology of titanium preparations, including ferrotitanium,

and uses. Reference is made to fusible clays containing about equal proportions of lime, silica, and titanium.

TUNGSTEN.—C. G. Fink (*The Mineral Industry*, 25, 720, 1917). An account of prices, production, and technology of tungsten, including ferro-tungsten, etc. Reference is made to the use of metallic tungsten as a catalyser for the production of ammonia from atmospheric nitrogen and hydrogen (U.S. Pat. 1,175,693, of Carl Bosch and Alwin Mittasch). A comprehensive bibliography of recent publications is appended.

URANIUM AND VANADIUM.—R. M. Keeney (*The Mineral Industry*, 25, 744, 1917). A brief account of the sources, metallurgy, uses, etc. Reference is made to the Standard Chemical Co.'s three patents (U.S. Pats. 1,201,625, 1,201,626, and 1,201,627, January 2nd, 1917) for uranium high-speed steel, and to some tests on its cutting qualities.

ZINC.—J. A. Zook (*The Mineral Industry*, 25, 748, 1917). An account of the production, imports, exports, prices, etc. Also special notes on the metallurgy of zinc by W. R. Ingalls, including references to the Simmonds retort discharging machine, the Simmonds hydraulic retort press, the types of distillation furnaces (Hegeler-Belgian furnaces being the predominant type in the United States, and Rhenish furnaces in Europe, though the author thinks the latter might well receive more consideration in the States where conditions are favourable to it), vertical retorts, briquetting, prereduction, reworking furnace residues, etc.

ORE DRESSING AND COALWASHING.—R. H. Richards and C. E. Locke (*The Mineral Industry*, 25, 781, 1917). A review of progress in 1916. The flotation process as applied to ore dressing continued to make remarkable advances, though the theory is a subject of much controversy; the two theories most favoured are surface tension and the electrical theory. Many recent articles bearing on flotation are briefly referred to, and there is also a very extensive general bibliography of recent publications relating to ore dressing and coal washing in 1916.

MINERAL STATISTICS.—(*The Mineral Industry*, 25, 844, 1917). Records in the form of tables referring to minerals, metals, and various products.

EXPORTS OF BAUXITE.
In metric tons.

Destination	1909	1910	1911	1912	1913
Russia	—	1·900	2·420	1·503	1·510
Sweden	—	—	20	—	—
Norway	—	—	20	—	1·825
Belgium	2·729	3·986	1·651	1·058	—
Great Britain ...	1·959	19·234	28·201	30·932	40·210
Italy	—	—	123	—	126
Germany	5·995	3·406	2·652	3·546	963
Holland	28·122	22·132	8·384	16·244	36·951
Austria	450	2·630	4·935	3·767	370
Switzerland ...	—	—	—	—	152
British India ...	—	—	6	—	—
Japan	21	—	17	—	—
United States ...	13·086	14·465	33·189	15·239	12·146
Totals	52·362	67·753	81·618	72·289	94·253

The above is from a typed appendix to A. de Keppen's pamphlet on bauxite. See TRANS., 16, *Abs.*, 33, 1917.

MAGNESITE IN AMERICA.—(*Engineering and Mining J.*, 105, 111, 1918). A reference to the working of deposits of magnesite in Stevens County, Washington, beginning in December, 1916. Previously magnesite in the U.S. was worked only in California. Magnesite quarries were also worked during 1917 in the Island of Margarita, Venezuela. The output from Canada is also alluded to.

ASBESTOS.—(*Engineering and Mining J.*, 105, 132, 1918). A note on the production for 1917. About 85 per cent. of the world's supply comes from the Thetford and Black Lake districts of Quebec (Canada), amounting in 1917 to about 140,000 short tons. In the U.S. asbestos was produced in 1917 in Arizona, California, Idaho, Georgiá, Vermont and Virginia. Chrysotile asbestos is worked in California (at Washington). Rhodesian deposits of asbestos were also worked.

GRAPHITE.—(*Engineering and Mining J.*, 105, 133, 1918). A report on supplies in 1917. Alabama's output is expected to prove more than double that of 1916, which in turn was 50 per cent. more than in 1915. New York's production is estimated at 5,500,000 lb. of flake graphite, representing a gain of nearly 50 per cent. on the previous year, or about double the normal total of earlier years. Texas graphite was not produced to any large extent during 1917. Artificial graphite continued to be produced at Niagara. Canadian graphite (from Quebec and Ontario Provinces) was produced in record quantities, that of Quebec, which is associated with sillimanite, gneiss, and crystalline limestone, amounting to over 400,000 lb., and that in Ontario to over 4,000 lb. Mexico, Madagascar, and Celyon (especially the latter) also furnished supplies.

GLASS.—(*Department of Commerce, U.S.A.*, 1917). Census for 1914, including general statistics relating to the manufacture of glass, special statistics relating to products and equipment, and detail statistics for the several states. Some comparative statistics for different years are also given.

CHROMITE IN 1916.—J. S. Diller (*Mineral Resources of the U.S., Pt. I*, 1917). An enormous increase in production is recorded. Particulars are given of prices and imports, and of chrome ore mining in the States and in Canada.

ASBESTOS IN 1916.—J. S. Diller (*Mineral Resources of the U.S., Pt. II*, 1917). Commercial details as to occurrence and production in certain States and in Quebec.

TALC AND SOAPSTONE IN 1916.—J. S. Diller (*Mineral Resources of the U.S., Pt. II*, 1917). Details of production in several States and of imports.

GRAPHITE IN 1916.—H. G. Ferguson (*Mineral Resources of the U.S., Pt. II*, 1917). Details of production and imports of crystalline, amorphous, and artificial graphite, also prices, exports, etc.

ABRASIVE MATERIALS IN 1916.—F. J. Katz (*Mineral Resources of the U.S., Pt. II*, 1917). Statistics of production and imports of natural abrasives including (1) millstones, chasers, dragstones, etc., (2) grindstones and pulpstones, (3) oilstones and scythestones, (4) corundum and emery, (5) abrasive garnet, (6) diatomaceous (infusorial) earth, tripoli and rottenstone, (7) pumice, (8) pebbles and lining for tube mills, but not abrasive quartz and felspar. Artificial abrasives are also dealt with, including (1) crushed crucible steel, crushed chilled iron, and crushed cast-iron, (2) the silicon carbides known as carborundum, crystolon, and carbolon, (3) the fused alumina sold as aloxite, alundum, exolon, and lionite.

SILICA IN 1916.—F. J. Katz (*Mineral Resources of the U.S., Pt. II*, 1917). Relates to the uses, production and imports of all kinds of silica—quartz, flint

or chert, etc.—including abrasive quartz, but excluding gem quartz, silica used for making glass, and silica used in the form of sand, gravel, and crushed material for building, for concrete and mortar, for foundry and furnace work, and for cutting and grinding stone.

SAND-LIME BRICK IN 1916.—J. Middleton (*Mineral Resources of the U.S., Pt. II*, 1917). A brief report with tables showing the value of sand-lime bricks sold in the States each year from 1903 to 1916, with details as to quantities in the last two years.

SAND AND GRAVEL IN 1916.—R. W. Stone (*Mineral Resources of the U.S., Pt. II*, 1917). Statistics for the several States, mostly tabulated, for production, imports, and exports, of glass sand, moulding sand, building sand, grinding and polishing sand, fire or furnace sand, engine sand, paving sand, filter sand, railroad ballast sand and gravel, other sands, and gravel. There is also a general review of glass sands (localities, requirements, etc.), moulding sand, etc.

GYPSUM IN 1916.—R. W. Stone (*Mineral Resources of the U.S., Pt. II*, 1917). Statistics of production for 1915 and 1916, certain details from 1912, and totals from 1907, with imports from 1912. The production of gypsum in Canada for 1915 and 1916 is also included.

CEMENT IN 1916.—E. F. Burchard (*Mineral Resources of the U.S., Pt. II*, 1917). Statistics relating to production of natural cement, Portland cement, and puzzuolan (slag-lime) cement from 1818, up to 1879, in ten-year periods, and from 1880 annually. For 1915 and 1916 production and shipments by States is shown. Particulars are given as to number and lengths of rotary cement kilns from 1913, as well as other practical details. The U.S. Government Specification for Portland cement (1917) is also printed, with brief references to the tests. Exports of hydraulic cement to different countries for 1915 and 1916 are shown in a table, and total exports annually from 1900, as well as cement imported from 1878 onward.

Finally there is a comprehensive bibliography of Government and State publications on cement materials, cement, and concrete, mostly by the Geological Surveys of the U.S. and of individual States, but including some by the U.S. Bureaus of Mines and Standards, the U.S. Department of Agriculture, etc.

IX.–HYGIENE. GOVERNMENT REGULATIONS.

HOME OFFICE REPORT ON THE MANUFACTURE OF SILICA BRICKS, &c.—(H.M. Stationery Office, 1917). Relates to the manufacture of silica bricks and other refractory materials used in furnaces, with special reference to the effects of dust inhalation upon the workers.

Analyses are given of certain silica rocks and fireclays. The manufacture of silica bricks is described, and also the manufacture of ganister bricks, ganister pug, ground ganister, as well as silica cement, silica flour or paint, furnace sand, etc.

Statistics are given concerning the high mortality from pulmonary phthisis among ganister workers, silica brick makers, etc.

The high mortality arises from inhalation of silica dust dispersed during the various processes involved in the manufacture and transport of bricks and other goods, and preparation of the raw materials. The means for prevention of dust inhalation are discussed, and regulations are recommended with a view to coping with the danger.

X.—GLASS

THE UNION OF GLASS IN OPTICAL CONTACT BY HEAT TREATMENT.—R. G. Parker and A. J. Dalladay (*Trans. Faraday Soc.*, 12, 305, 1917). The surfaces of each of two pieces of glass are so worked and polished

that they are either both plane or of the same curvature to a very high degree of accuracy. They can then be placed together in "optical contact," and if they are subjected to carefully controlled heating will unite and become one piece. The temperature at which union takes place must be not only far below the melting point of the glass, but also below the annealing temperature, for even at this temperature very slight strain will cause sufficient deformation of worked glass surfaces to render them useless.

The question is discussed theoretically, and details of experiments are given. Fused silica behaves essentially like glass in this respect.

FORMATION AND REMOVAL OF BUBBLES IN MOLTEN GLASS.—R. M. Howe (*Trans. Amer. Cer. Soc.*, 19, 201, 1917). There are four classes of bubbles found in glass:—(1) Bubbles arising from the decomposing ingredients of the batch, which bubbles may contain CO, CO_2, SO_2, SO_3, oxygen, oxides of nitrogen, etc. The substances forming such bubbles will exert an enormous vapour pressure at the firing temperature. These gases are all rather insoluble in glass at this temperature, and as they are unable to escape they remain in the glass as bubbles or "seeds." (2) Bubbles resulting from the volatilizing of some of the ingredients of the batch, such as common salt. These substances are in general more soluble in the glass, and have not such high vapour pressure. (3) Bubbles which result from ingredients added to the melted glass, as a potato, or arsenic. Their vapour pressures are very high, and the rate of solution (if soluble at all) is low. Such substances hardly go into solution, but volatilize rapidly and form bubbles. (4) Bubbles introduced by accident, as those evolved during reheating or introduced during gathering, etc.

The principles controlling the removal of bubbles are discussed, and summarised as follows: (*a*) The removal of bubbles depends upon the frictional resistance of the glass and the square of the radius of the bubble. If x equals the rate then $x = Ar^2/K$, K being the frictional constant. (*b*) K can never be made negligibly small, therefore extremely small bubbles cannot be entirely removed by increasing the temperature, K can simply be made as small as is practical. (*c*) After K is made sufficiently small the radius of the bubble must be greater than a certain minimum value before the bubble will rise. (*d*) Expansion of bubbles by increasing the temperature will not remove all bubbles. (*e*) The most certain way to assure the removal of all bubbles is by the introduction of large bubbles. The small bubble then passes into the larger one and passes out with it.

GLASS SANDS.—C. R. Fettke (*Trans. Amer. Cer. Soc.*, 19, 160, 1917). At the present time very nearly pure quartz sands, made up almost entirely of little grains of quartz varying in size from 0·1 to 0·4 mm. in diameter, furnish practically the only source of silica for the glass industry.

The occurrence and modes or origin of sands and sandstones are considered, and the effects of various impurities are discussed. Reference is also made to the influence of size and shape of grains, and to the treatment of sandstones and quartzites for glass making, including appliances for washing the sand. Although angular particles are to be preferred if other factors are the same, because they present greater surface for chemical action during the melting operation, excellent results have been produced when the grains were rounded. A table is given showing the percentage of the various sized grains in five typical glass sands. Most manufacturers use sand which will pass a 30-mesh (per linear inch) sieve but will not pass a 120-mesh sieve, the size of the grains ranging between 0·136 and 0·64 mm. in diameter. Finer particles are apt to produce greater loss through draught, especially in tank furnaces.

GLASS TANK-FURNACE OPERATION.—R. L. Frink (*Trans. Amer. Cer. Soc.*, 19, 331, 1917). A brief discussion of some difficulties which may arise—such as seeds and bad colour—through unsuitable features connected with the construction of the furnace.

MANGANESE IN GLASS USED AS A DECOLORIZER.—(*Trans. Amer. Cer. Soc.*, 19, 370, 1917). A discussion as to the condition in which the manganese exists, and of the causes which produce green glass by the "burning out" of manganese. The latter is attributed by some to too sharp or too highly oxidizing fire, by others to too soft or reducing fire. It has been proved that reducing gases within the furnace will produce the green colour, completely oxidizing conditions a clear water-white, and neutral or inert condition produces a pink to a violet tint. It has been stated that increase of lime and magnesia relative to silica in the glass makes the effect of manganese more pronounced and sensitive to fire conditions, while the higher the soda content in the glass as related to silica the less effective becomes the manganese, but the more stable the colour under certain conditions. Reference was made to work of Dr. S. R. Scholes, indicating that the pink colour is due to trivalent manganese.

SELENIUM GLASSES.—O. N. Witt (*Berichte der Technisch-wissenschaftlichen Abteilung des Verbanaes keramischer Gewerke in Deutschland*, 2, 43, 1914). Reference is made to D.R.P. 63,558 of Welz in 1891 for giving a rose colour to glasses by addition of selenium, and the D.R.P. 74,565 of Dr. Spitzer in 1893 for colouring glass by selenium compounds. These inventions were of great importance, because the green coloration of glass due to traces of iron may be compensated physically by the rose colour producible by selenium. Such physical decoloration of glass is far more reliable than by the use of manganese, which latter by long continued action of light loses its power, as is proved by the frequent violet coloration of old window panes.

It is not yet decided with certainty whether the colours produced by the related element sulphur—ranging from light yellow to blackish brown—depend on the presence of elementary sulphur or of polysulphides. Probably both act, and perhaps the yellow colours are due to sulphur, and the blackish browns to polysulphides or to colloidal iron sulphide.

It is probably a matter of indifference whether selenium is added to the glass mixture in the elementary condition (according to Welz), or as selenites or selenates (like Spitzer). Very small quantities of selenium suffice to give a rose colour to the glass, which colour is not strengthened beyond a certain limit by certain additions. Hence selenium can be used, notwithstanding its high price, as a decolorising agent.

The well known fact that other elementary glass-colouring materials, especially gold and silver, are contained in the glass in colloidal form suggests that in rose colouring by selenium a colloidal solution of this element in the substance of the glass must be brought about, a view which has been expressed by the author for more than ten years, though it has only been discussed publicly since last year, by Fenaroli and others. Before the appearance of Fenaroli's works, the author's assistant, Fränkel, had already studied the behaviour of selenium in glass technology, and in the course of the last year and a half had collected a whole series of facts, of which a preliminary notice is here communicated.

The quantity of selenium found to be present in samples of glass averaged 0·021 per cent., and the amount actually concerned in colouring the glass was found to be 0·0016 per cent., or only about 8 per cent. of the selenium present. It was ascertained that at about 620° the colour of a selenium glass almost entirely vanished, returning again on cooling. The finest rose colour is got with potash glasses. The higher the content of the glass in bases the more brownish the colour becomes.

Glass takes up at most 0·06 per cent. of selenium, all beyond this being volatilized in alkali-lime glasses. Alkali-lead glasses take up more selenium, but become blackish brown from lead selenide. Free selenium is volatile at 120°, and it would seem better to introduce it as alkali-selenite, or selenate. In the discussion it was stated that good results had been obtained for ceramic colours.

STRAIN IN GLASS.—H. Schulz (*Berichte der Technisch-wissenschaftlichen Abteilung des Verbandes keramischer Gewerke in Deutschland*, 2, 48, 1914). A discussion of the conditions which give rise to strains in different types of glass.

GLASS-COLOURING MATERIALS.—M. F. (*Ker. Rund.*, 23, 30, 1915). A brief discussion of the substances used, particularly for bottles. Manganese, copper, chromium, and cobalt compounds are referred to, and also tin oxide and bone ash.

ENGLISH GLASS FOR LABORATORY VESSELS.—(*Ker. Rund.*, 23, 247, 1915). Abstracted from "The Chemical Trade Journal," 351, 1915, giving the composition of various glasses as reported by the Institute of Chemistry Glass Research Committee.

MELTING GLASSES.—F. M. (*Ker. Rund.*, 23, 147, 172, 184, 202, 1915). A discussion of the qualifications desirable in those who have to carry out the melting operations.

POTASSIUM PERMANGANATE AS SUBSTITUTE FOR NITRE IN THE GLASS INDUSTRY.—L. Springer (*Ker. Rund.*, 23, 214, 1915). A discussion of the possibility of using it. The conclusion is that from its properties it should be a good substitute for nitre as oxidizing and purifying agent, and that it can also be used advantageously as a decolorant and as a colouring material for violet. Practical tests in glass works are necessary.

YELLOW COLORATION OF POLISHING SILVER (ON THE BACK).—L. Springer (*Ker. Rund.*, 23, 159, 177, 190, 207, 1915). The author concludes that in all kinds of polishing silver examined the yellow coloration depends on the burning-in temperature, and that the burning-in should take place at as low as temperature as possible, that is, at dark-red heat (cone 022), and enamels etc. which need a higher temperature should not be burned at the same time, as otherwise the silver may be burned into the glass and give the yellow tint. The best forms of silver to use are silver carbonate and pure fine grey silver powder without lustre (probably amorphous). Shining silver powder (probably crystalline) and silver powder containing copper are bad. The kind of flux—whether bismuth oxide or lead borate, for example—seems to have no particular influence.

CAUSES OF FRACTURE OF GLASS AND ITS PREVENTION.—F. M. (*Ker. Rund.*, 23, 121, 1915).

INFLUENCE OF ALUMINA ON FUSIBILITY OF GLASSES.—F. Singer (*Ker. Rund.*, 23, 65, 78, 95, 103, 1915). An investigation to ascertain the most suitable proportions of silica, alumina, lime and alkalies. The alumina was introduced by means of two German pegmatites, which though high in silica contain felspar as well, the alkali of which enables some saving to be effected.

Pegmatite I has 75·95 per cent. SiO_2, 13·01 Al_2O_3, and 9·34 alkalies. The usual normal composition of ordinary window glass was taken as a basis, viz.:

$$\left.\begin{matrix}0{\cdot}4\text{—}0{\cdot}6\ CaO\\ 0{\cdot}6\text{—}0{\cdot}4\ Na_2O\end{matrix}\right\}\ 2{\cdot}5\text{—}3{\cdot}0\ SiO_2,$$

and two series of trials were prepared corresponding to

$$\left.\begin{matrix}0{\cdot}4\ CaO\\ 0{\cdot}6\ Na_2O\end{matrix}\right\}\ 2{\cdot}6\ SiO_2 \text{ and } \left.\begin{matrix}0{\cdot}5\ CaO\\ 0{\cdot}5\ Na_2O\end{matrix}\right\}\ 2{\cdot}6\ SiO_2$$

To these were added varying amounts of alumina, represented by the molecular fractions 0·263, 0·200, 0·150, 0·100, and 0·05, and some mixtures were melted without any alumina content, for comparison. A trial of each was subjected to temperatures of 950° C., 1,150° C., 1,230° C., and 1,420° C. respectively. Pegmatite I itself at 950° gave a loose white powder, at 1,150° and 1,230° it was sintered hard and forms a white coherent product, which at 1,420° is melted. This melted product is glassy, but neither transparent nor decidedly translucent. All the mixtures at 1,420° were melted to transparent and clear glasses, slightly coloured by the iron, but no more than ordinary window glass. The colour due to the ferrous oxide in glasses with strong alkali content was found to incline to blue, whilst with less alkali and greater lime content it tended more to green. No difference in fusibility was recognised at 1,420°. At 1,150° and 1,230° the mixtures with small alumina content melt earlier.

more easily, and clearer than the corresponding glasses without alumina, particularly in the case of those with the larger proportion of alkalies. The most fusible of all was the mixture with least alumina and most alkali. It is proved again that a little alumina increases the fusibility, whilst a larger amount decreases it. Most of the mixtures were melted completely at 1,230°.

Pegmatite II has 93·61 per cent. SiO_2, 3·51 Al_2O_3, and 1·89 K_2O.

Three series were prepared with this, two of them as before, and the third $\left.\begin{matrix}0{\cdot}6\ CaO\\0{\cdot}4\ NaKO\end{matrix}\right\}$. Each of the three was compounded with different proportions of silica, namely, 2·5, 2·75, and 3·0 SiO_2. The amount of alumina fluctuated between 0·0555 Al_2O_3 and 0·067 Al_2O_3.

The mixtures were treated as before, the temperatures used being the melting points of Seger cones 1, 4, 7, 9, 12 and 14—15. The colour effects were practically as before in all respects.

In these three parallel trials the differences of the non-aluminous and aluminous fusions is the greater the more silica the fusions contain. With RO consisting of $0{\cdot}5\ CaO+0{\cdot}5\ Na_2O$, and with 2·5 and 2·75 SiO_2 no difference was found between the aluminous and non-aluminous glasses, though there was a difference with 3·0 SiO_2. In the case of normal glass [according to Schwarz] ($0{\cdot}5\ CaO+0{\cdot}5\ Na_2O$), 3·0 SiO_2, at cone 14—15 only an opaque frit is produced, whereas with alumina it is a well melted glass at the same temperature. With still higher alkali content, neither favourable nor injurious effects of the alumina were observed.

No one of the aluminous melts was worse than the corresponding non-aluminous melt. In the series with $0{\cdot}6\ CaO+0{\cdot}4\ Na_2O$ differences occur even with 2·5 SiO_2, and increase with increase of SiO_2 up to 3·0 SiO_2, and always in favour of the aluminous glasses.

The investigation shows that with glasses containing alumina comparatively more lime and silica can be introduced than in non-aluminous glasses. Besides this possible economy in alkali, the use of pegmatite also saves some of the soda.

INFLUENCE OF ALUMINA ON FUSIBILITY OF GLASSES.—L. Springer (*Ker. Rund.*, 23, 271, 280, 1915). Exception is taken to Singer's conclusion that alumina itself up to a certain limit makes glass more easily fusible. The author contends that it is not to the introduction of a certain quantity of alumina that the glasses owe their easier fusilibity, but to the circumstance that a part of the sand was substituted by pegmatite, which is itself much more easily fusible and contains some alkali already combined with silica.

Exception is also taken to Singer's statement that the normal composition of ordinary window glass is:

$$\left.\begin{matrix}0{\cdot}4—0{\cdot}6\ CaO\\0{\cdot}6—0{\cdot}4\ Na_2O\end{matrix}\right\}\ 2{\cdot}5—3{\cdot}0\ SiO_2.$$

According to the Tscheuschner formula commonly used in the glass industry, in which $CaO=1$, and taking the extreme values for the silica, the above and the others with soda and lime varied would become:

$1{\cdot}5\ Na_2O : 1\ CaO : 6{\cdot}25\ SiO_2$	(I)	$1{\cdot}5\ Na_2O : 1\ CaO : 7{\cdot}5\ SiO_2$	(IV)
$1\ Na_2O : 1\ CaO : 5\ SiO_2$	(II)	$1\ Na_2O : 1\ CaO : 6\ SiO_2$	(V)
$0{\cdot}67\ Na_2O : 1\ CaO : 4{\cdot}17\ SiO_2$	(III)	$0{\cdot}67\ Na_2O : 1\ CaO : 5\ SiO_2$	(VI)

According to Benrath, Weber, Tscheuschner, and many others, the normal composition of good alkali glasses (so-called Tscheuschner normal formula) is:

$$1Na_2O : 1CaO \cdot 6SiO_2$$

with the amplification that without detriment to the quality a greater alkali content is permissible with higher silicification, while higher lime content

requires a silica content below the trisilicate. The latter substitution comes in the amplified Tscheuschner glass formula to the expression:

$$x\ Na_2O : y\ CaO : \left.\frac{x^2}{y} + y\right) SiO_2.$$

Glass V corresponds to the normal formula itself. Glasses III and VI approximate. The other glasses are too rich in alkali or too poor in silica.

Window glasses have more usually somewhat less alkali and silica, but more lime, than corresponds to the normal formula, by which the lustre of the glass is increased, and the expensive alkali saved. Weber found the composition of approved window glasses within the limits:

$$0{\cdot}6\ Na_2O : 1\ CaO : 3{\cdot}8—4{\cdot}4\ SiO_2$$
$$\text{and } 0{\cdot}9\ Na_2O : 1\ CaO : 4{\cdot}8—5{\cdot}3\ SiO_2$$

GLASS.—Sir H. Jackson (*J. Soc. Glass Tech.*, 1, 140, 1917). Some general observations. After fusing *in vacuo*, glass did not crystallize on cooling, but on admission of a little water the glass crystallized readily. This suggested that no pure glass would crystallize, but in practice water vapour is always present above the glass. A non-homogeneous glass may also tend to crystallize. Opal glasses are due to separation of silica in the colloidal form. The size of the molecules altered as this change proceeded. Very similar changes occurred in the production of coloured glasses through the use of gold, copper, carbon, selenium, sulphur and ferric iron. The formation of a colloidal solution with ferric iron seems clear. Ferrous iron gives ferrous silicate, which is green; ferric iron given ferric silicate, which is white. Ferric oxide is yellow, and the yellow colour of glass due to iron is due to ferric oxide in colloidal form separating out on cooling.

For obtaining coloured glass it should be remembered that some materials —like boric oxide—acted as solvents for colouring matter, so that it is not easy to strike a colour when they are present. For opals the glass must be homogeneous.

The volatility of the components of a glass must not be forgotten, even silica being lost to a slight extent from a glass furnace.

ACTION OF SODIUM HYDROXIDE SOLUTION ON GLASS.—G. W. W. Way, J. D. Cauwood, and W. E. S. Turner (*J. Soc. Glass Tech.*, 1, 144, 1917). It was found that the corrosive action of 2N-caustic soda increased rapidly with temperature above 20°, especially between 90° and 100° C., the rate of increase for this interval of 10° being about 150 per cent.

AMERICAN HIGH-GRADE GLASS-SANDS.—P. G. H. Boswell (*J. Soc. Glass. Tech.*, 1, 147, 1917). The crushing, screening, washing, and drying of the sands are carried out more carefully and thoroughly in America than here, the quarrying and treatment being on a large scale and apparently with better transport facilities. The glass-sands are obtained by treatment of friable sandstones ranging from Cambrian quartzite to Carboniferous sandstone, whereas all the best West European glass-sands (British included) come from Tertiary deposits. Practically no compound grains are present in these American glass-sands, all being highly quartzose and none very aluminous, while alkalies are practically absent. The iron-content is remarkably uniform at 0·02 per cent. Descriptions with analyses are given of samples from six different sources.

ATTACK OF CHEMICAL REAGENTS ON GLASS SURFACES, ETC.—J. D. Cauwood, S. English, and W. E. S. Turner (*J. Soc. Glass Tech.*, 1, 153, 1918). The historical development of chemically resistant glass is traced, after which the resistant properties which glass should exhibit under different conditions of use are discussed, followed by an enumeration of methods for testing the durability of glass. The work of previous investigators is then reviewed, and then the investigations of the authors are described, the paper being brought to a conclusion with a general discussion of the results. It seems desirable to test the resisting power of a glass not merely to water, but also at

least to caustic alkali, sodium carbonate, and hydrochloric acid. The results of tests on glasses of given composition are compared. Taking all the tests into consideration, all the British glasses on the market are included in the six best, and Jena glass comes seventh.

SEMI-AUTOMATIC GLASS-MAKING MACHINERY IN AMERICA.—R. E. McCauley (*J. Soc. Glass Tech.*, 1, 203, 1917). A brief account of the different classes of machines: window glass machinery, máchines for making electric bulbs and the similar but larger paste-mould machines; presses to replace the old side-lever press; press and blow machines where the parison is first pressed and then transferred to the finish mould, where it is blown to its ultimate shape; and the machine for making narrow-mouthed bottles (such as sodas, medicals, etc.) The author states that most managers are quite successful with the use of semi-automatic machinery, whilst a few fail with it.

SOME COMMON PROBLEMS IN MELTING AND WORKING GLASS.—W. E. S. Turner (*J. Soc. Glass Tech.*, 1, 210, 1917). A short discussion of two questions: I. The substitution of salt-cake by soda. II. The relative sizes of gas and air ports.

A BIBLIOGRAPHICAL CONTRIBUTION TOWARDS THE STUDY OF THE DURABILITY OF GLASS.—W. E. S. Turner (*J. Soc. Glass Tech.*, 1, 213, 1917). Comprehensive lists of contributions to various journals, and other publications, bearing on the subject.

NEW BLOWPIPE BURNER USING PREHEATED GAS MIXTURE.—W. A. Whatmough (*J. Soc. Glass Tech.*, 2, 3, 1918). The actual working of the instrument was shown, and the construction explained. The burners are patented and are made by the James Keith & Blackman Co., London.

GLASS-MAKING AT BOLSTERSTONE, NEAR SHEFFIELD.—J. Kenworthy (*J. Soc. Glass Tech.*, 2, 5, 1918). An historical account, from about 1650 to 1750.

GLASS POT FAILURE.—S. N. Jenkinson (*J. Soc. Glass Tech.*, 2, 13, 1918). A short account of observations on pots in use, with special reference to fritting or honeycombing, external cracking, batch cracks (internal), holing, and excessive solubility of bottoms. The following conclusions were drawn:—(1) That a high temperature (short of softening) is not detrimental to a glass pot. (2) That an aluminous clay at a high temperature stops pitting. (3) That a siliceous clay, even with a high temperature, causes pitting. (4) That sudden temperature changes cause cracks. (5) That batch cracking can be decreased by using thinner pots. (6) That "holing" is caused by the presence of iron pyrites in the clay. (7) That the bottom of a pot does not resist the action of the glass so well as the sides.

It is also inferred that the presence of sillimanite in the pot is important and that it acts as a protective coating.

AMERICAN METHODS AND PRACTICE IN THE GLASS INDUSTRY.—H. H. Pitt (*J. Soc. Glass Tech.*, 2, 19, 1918). Notes relating to fire-polishing, attention to presses and moulds, the O'Neill semi-automatic machine for wide-mouthed bottles, the Mason fruit jar, the Owens and other bottle-making machinery, the Westlake and Corning bulb-blowing machines, and machinery for sheet-glass.

NEW VARIABLE JET BLOWPIPE.—S. English (*J. Soc. Glass Tech.*, 2, 30, 1918). An illustrated description. Three separate jets are provided, small, intermediate, and larger.

RESISTANT POWER OF HEAVY LEAD-POTASH GLASS TO CHEMICAL AGENTS.—J. D. Cauwood, W. E. S. Turner, and D. Webb (*J. Soc. Glass Tech.*, 2, 32, 1918). The action of boiling water, water at 183° C., boiling hydrochloric acid, 2N sodium hydroxide, and 2N sodium carbonate solution were studied. The results of the tests were summarized in

a table, in which are also included corresponding figures for the best British chemical glasses now in use and for Jena laboratory glass.

The heavy lead-potash glass possesses extraordinary resistant power to water, even up to a high temperature. Towards acid and alkalies it is not so good, but on the whole is distinctly superior to Jena glass, the latter being better only as regards 2N sodium carbonate. With rise of lead content the resistant power of glass towards water appears to rise rapidly, though the susceptibility towards acids and alkalies increases at the same time. No chemical glass on the market at the present time equals the heavy lead glass as regards resistance to water up to a high temperature.

POTS FOR MAKING PLATE-GLASS.—C. H. Kerr, U.S. Pat. 1,217,956, March 6th, 1917. Pots for molten glass are made of ordinary pot clay mixed with 8 to 30 per cent. of fine-grained pure silica sand (most of the particles being less than 0·05 in. in diameter). The durability of the pots is increased by the sand added.

MAKING GLASS AND HCl.—W. Glaeser, U.S. Pat. 1,234,457, July 24th, 1917. A mixture of 100 parts sand, 26 limestone, 41 sodium chloride and 15 carbon is heated with steam in an open kiln to 800° to produce window glass with HCl as a by-product.

PORCELAIN POTS FOR MELTING OPTICAL GLASS.—(*Chem. and Met. Eng.*, 19, 47, 1918). In making optical glass decolorizing is not permissible, so the iron content of the pot mixture should be kept low to avoid contamination of the glass, especially in the fusion of barium glasses which in the presence of iron oxide readily assume a green colour detrimental for photographic purposes. The commercial pots are found to be unsuited for this work. The Bureau of Standards optical glass laboratory at Pittsburgh has produced a mixture which resists even the very corrosive action of heavy barium crown glass, hitherto destructive to every kind of pot tried.

The mixture is virtually a porcelain, and the pots must be heated to about 1,400° C. before being charged with the glass mixture. This will insure vitrification of the body and density of structure. The best results have been obtained with the following:—

White ware pottery bisque, ground and screened to pass 10-mesh sieve	35
Pot shell (from used porcelain pots)	10
Felspar	3
Potters' flint	4
Tennessee ball clay	15
Illinois bond clay	5
Georgia kaolin	8
Florida kaolin	8
North Carolina or Maryland kaolin	12
	100

The pottery bisque is the waste unglazed material rejected in the manufacture of so-called white table ware—not porcelain (whether for table ware, floor tile, or electrical insulators) which is not refractory enough.

The glass pots have been very successfully produced by casting, without using skilled labour. About 0·2 per cent. of a mixture of sodium silicate and sodium carbonate is added to the body mixture, and the thick but fluid mixture is poured into suitable plaster moulds, each provided with a core. The plaster absorbs the water very readily and causes the mass to stiffen after about 16 hours when the core can be removed. The mould can be taken apart after about 24 hours. The pots thus made have been found to dry very readily, so that in many cases they can be placed in the furnace in from 4 to 6 weeks. Usually this process requires 3 to 4 months. The cast pots, which have been used with great success in the melting of optical glass and proved superior to

the hand-made pots owing to uniform structure, have been made from the following :—

White-ware pottery bisque, through 10-mesh	48
Tennessee ball clay	15
Illinois bond clay	8
Felspar	5
Georgia kaolin	7
Florida kaolin	7
North Carolina or Maryland kaolin	10
	100

A figure is given of a plaster mould for casting glass-pots.

XI.—CEMENTS, MORTARS, CONCRETE, Etc.

HIGH-SILICA PORTLAND CEMENT.—A. W. K. Billings (*Proc. Amer. Soc. for Testing Materials*, 17, Pt. II, 239, 1917). See abstract of *Preprint*, Trans., 16, *Abs.*, 126, 1917. There is added a short discussion by S. B. Newberry.

CEMENT-LIME-SAND-MORTARS.—W. E. Emley (*Proc. Amer. Soc. for Testing Materials*, 17, Pt. II, 261, 1917). A general review of the properties, as indicated by tests, specified in the abstract of *Preprint*, Trans., 16, *Abs.*, 125, 1917. A discussion is appended.

PORTLAND-CEMENT MORTARS AND CONCRETES.—J. A. Kitts (*Proc. Amer Soc, for Testing Materials*, 17, Pt. II, 279, 1917). See abstract of *Preprint*, Trans., 16, *Abs.*, 125, 1917. A critical discussion follows.

SANDS AND CONSISTENCY OF CONCRETES.—L. N. Edwards (*Proc. Amer. Soc. for Testing Materials*, 17, Pt. II, 301, 1917). See abstract of *Preprint*, Trans., 16, *Abs.*, 124, 1917. A discussion follows.

COMPRESSIVE STRENGTH OF CONCRETE.—D. A. Abrams (*Proc. Amer. Soc. for Testing Materials*, 17, Pt. II, 364, 1917). See abstract of *Preprint*, Trans., 16, *Abs.*, 124, 1917. A discussion follows.

TESTS OF CONCRETE SLABS.—A. N. Johnson (*Proc. Amer. Soc. for Testing Materials*, 17, Pt. II, 378, 1917. See abstract of *Preprint*, Trans., 16, *Abs.*, 124, 1917. A discussion follows.

TESTS OF CONCRETE ROAD AGGREGATES.—J. P. Nash (*Proc. Amer. Soc. for Testing Materials*, 17, Pt. II, 394, 1917). Illustrated description of tests with tabulated results, and general conclusions.

REINFORCED CONCRETE.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 201, 1917). Final report of Joint Committee on Concrete and Reinforced Concrete. Deals with uses, materials, mixing and placing, forms, design, working stresses, etc.

THE MECHANISM OF THE SETTING PROCESS IN PLASTER AND CEMENT.—C. H. Desch (*Trans. Faraday Soc.*, preprint, 1918). The now well understood process of setting in the case of plaster, and certain other substances is first considered, and then simple mortars. Then the more complicated case of the setting of Portland cement is discussed at some length, reference being made to the evidence afforded by polished and etched surfaces, and to the results of other modern investigations.

The action of catalysts needs further study.

SETTING OF CEMENT.—J. G. A. Rhodin (*Trans. Faraday Soc.*, preprint, 1918). The author discusses whether it is mainly a physical or a chemical process. The setting of cements made from felspar residues is closely analogous to the re-formation of zeolite crystals, by simple immersion in water, after being made dull and opaque by heating. The Author found that by adding 0·5 per cent. of aluminium sulphate or alum before firing a slag cement or a felspar cement, it could be made to keep as well as any other, instead of reverting to inactive silicates as sometimes happens with such cements when stored.

THE CONSTITUTION AND HYDRATION OF PORTLAND CEMENT.—A. A. Klein (*Trans. Faraday Soc.*, preprint, 1918). Portland cement may be defined as the product obtained by pulverizing to a sufficient and definite fineness the clinker produced by an incomplete fusion of a finely ground intimate mixture, containing essentially lime, silica, and alumina in certain definite proportions. Iron, magnesium, sodium and potassium oxides are present almost universally in the product, although they are apparently not at all essential.

Portland cement within the composition limits considered good practice was found to be a mixture of Beta $2CaO.SiO_2$, $3CaO.SiO_2$, and $3CaO.Al_2O_3$. Free lime does not occur except in underburned clinker, and the presence of $5CaO.3Al_2O_3$ may result from underburning or from raw material low in lime and high in alumina. The alite of earlier investigators was apparently a mixture of $3CaO.SiO_2$ and $3CaO.Al_2O_3$, and celite was probably $2CaO.SiO_2$ or an intimate mixture of $2CaO.SiO_2$ and $3CaO.Al_2O_3$. In actual practice free lime is usually present in small quantities.

The hydration of cement is brought about by the formation of amorphous hydrated tricalcium aluminate with or without amorphous alumina, the aluminate crystallizing later. At the same time sulpho-aluminate crystals are formed, and any free lime is hydrated. These compounds begin to be formed soon after the cement is gauged with water. Within 24 hours tricalcium silicate begins to be hydrated, and after a week or more the amorphous aluminate begins to crystallize and beta-orthosilicate begins to hydrate. This latter is the chief constituent of the American Portland cements.

The ideal cement should possibly have an excess of the dicalcium silicate, which would give a not too dense hydrated material, gaining strength later. A lesser amount of the tricalcium silicate would give the desired early strength and also overcome the excessive porosity of the dicalcium silicate.

THE SETTING AND HARDENING OF PORTLAND CEMENT.—G. A. Rankin (*Trans. Faraday Soc.*, preprint, 1918). Portland cement is the result of chemical combination of three essential components, lime, alumina, and silica, but magnesia and ferric oxide are always present to some extent in commercial cement. A pure Portland cement when perfectly burned is made up of dicalcic silicate, tricalcic silicate, and tricalcic aluminate, but if not perfectly burned the clinker may also contain besides these major constituents two minor constituents in the form of free lime and the aluminate $5CaO.3Al_2O_3$. The first silicate formed is dicalcic silicate, which afterwards with great difficulty takes up more lime to form tricalcic silicate, this latter being the most essential constituent of Portland cement. The first aluminate formed is $5CaO.3Al_2O_3$, which afterwards unites with more lime to form tricalcic aluminate.

The setting and hardening of Portland cement involves the formation of an amorphous hydrated material which subsequently partly crystallizes. The initial set is probably due to hydration of tricalcic aluminate, the hardness and cohesive strength at first are due to the cementing action of the amorphous material produced by the aluminate and of tricalcic silicate, and the gradual increase in strength is due to further hydration of these two compounds, together with the hydration of dicalcic silicate. Tricalcic silicate is apparently the essential constituent of Portland cement, probably because gelatinous silica is so readily released when it is mixed with water.

The possibility is suggested of finding some solution or electrolyte which will release hydrated silica readily from dicalcic silicate.

CRYSTALLOIDS AGAINST COLLOIDS IN THE THEORY OF CEMENTS.—H. Le Chatelier (*Trans. Faraday Soc.*, preprint, 1918). The author briefly discusses the characteristics of colloids and the setting of plaster. He then expounds his own similar explanation of the setting of cements, which was given 30 years ago, and which he thinks still meets all the requirements of the case.

EFFECT OF SLAG ON THE SETTING PROPERTIES OF PORTLAND CEMENT.—E. Deny and E. H. Lewis (*Trans. Faraday Soc.*, preprint, 1918). The authors found that mixtures of 70 cement (of various well-known brands) with 30 granulated slag almost invariably set more slowly and acquired greater tensile strength than the neat cement. They also found it possible to use with safety an unusually high percentage of lime in the clinker, the addition of suitable slag to such clinker giving a cement of reasonably slow setting time and of great strength. This result they attribute to the presence of much "alite," formed owing to the high content of lime.

The quick setting and quick hardening are ascribed to abundance of the colloid first formed by the hydrolysis of calcium aluminate, and the favorable influence of this colloid on the subsequent formation of a colloid by the hydrolysis of the silicate of lime.

THE SETTING OF CEMENT IN ITS RELATION TO ENGINEERING STRUCTURES.—B. Blount (*Trans. Faraday Soc.*, preprint, 1918). The author sums up by stating that little is known about the mechanism of setting, save in the case of plaster of Paris. Portland cement is tested for setting time neat and is never used neat, and there is no quantitative relation between its setting time neat and its setting time in concrete. The conclusion naturally follows that much earnest and thoughtful work must be done before we can arrive at anything which can be accepted generally as proved—not by authority, or as it were of faith, but *proved*.

ANCIENT AND MODERN MORTAR.—W. J. Dibdin (*Trans. Faraday Soc.*, preprint, 1918). Properly compounded modern mortars will within a reasonable time possess strength equal to the best old samples obtainable. Proportions of lime to aggregate are generally given in terms of *unslaked* lime by *volume*, and in stating the results of analyses of mortar the volume of lime is calculated from the percentage of pure CaO on the assumption that the original lime was comparable to a commercial lime containing 80 per cent. CaO, and multiplying the weight so found by $2\frac{1}{3}$, to correct *weight* to *volume*. Analyses of 26 ancient mortars showed volume of aggregate to one volume of lime to vary from 0·4 to 3·7, being over 2 in only 4 instances; the average was about 1 as compared with the modern practice of 3. As aggregate were used materials conveniently obtainable, preference being given to clean ferruginous, clayey, gravelly sand when available. Soluble silicates do not seem to be formed.

Graham ascribed the setting of mortar to form a hard mass solely to aggregation of the particles without any chemical combination between the lime and the sand. He considered the fixing of hydraulic mortar to be chiefly due to fixation of the water and formation of a solid hydrate like gypsum. The author's experience confirms this view, and he has no doubt that the process of crystallization acts largely in connection with the "setting" of mortar and cement, assisted by aggregation.

MEASURING TIME OF SET OF CALCINED GYPSUM.—W. E. Emley (*Trans. Amer. Cer. Soc.*, 19, 573, 1917). From results of careful and comprehensive investigation the following method is recommended for determining the time of set of calcined gypsum or of prepared plaster made therefrom. Determine first the normal consistency using the Southard instrument, as recommended by Sub-committee 4 of Committee C-11, American Society for Testing Matrials. Ascertain from this the amount of water to be added to 100 grams of the sample to produce a paste of normal consistency. Put 3 times this amount of distilled water into a perfectly clean porcelain casserole. Transfer 300 grams of the sample to a clean sheet of glazed paper. Transfer the sample

from the paper—as quickly as possible without splashing, but within 2 seconds —to the casserole. After just 60 seconds from commencement of transfer the soaking mixture is to be stirred vigorously by means of a clean glass rod (about $\frac{1}{8}$ in. diameter) for one minute to make the mass homogeneous. At the end of the second minute the mixture should be poured into the mould for the Vicat needle, and at one minute intervals the needle is allowed to sink into the paste. The time elapsed between the time when the sample was added to the water and the time when the needle no longer penetrates to the bottom is recorded as the time of set.

The sample, water, casserole, and mould shall be at a temperature not below 20° C. nor above 25° C. at the beginning of the experiment. The Vicat needle and the mould are described in the standard specifications for cement at p. 359 of the 1915 Year-book of the American Society for Testing Materials. The mould is made of hard rubber and should be prepared for use by dipping it in melted paraffin, so that it can be thoroughly and easily cleaned by gently heating.

EFFECT OF FROST ACTION ON SAND.—C. A. Ferry (*Proc. Amer. Soc. Civil Eng.*, 42, 1,520, 1916). To test the effect of frost action on heaving the sand foundation under the Yale concrete bowl, a sample of sand taken after a heavy rain and having 23 per cent. of the voids filled with water was tested by freezing. There was not sufficient expansion to crack a small glass bottle until 75 per cent. of the voids were filled with water. The capillary effect in retaining water was small, and it was inferred that any expansion due to water freezing through the expansion joints in the concrete was negligible.

USE OF HYDRATED LIME IN CONCRETE.—H. E. Wiedmann (*J. Eng. Club, St. Louis*, 1, 161, 1916). 5 to 10 per cent. of calcium hydroxide increases the plasticity of the mass, reduces the amount of water necessary for flowing in chuting, increases the density, makes the concrete more water-tight with reduction of expansion and contraction to a minimum, and with $\frac{1}{3}$ mortars up to 10 per cent. of calcium hydroxide increases the strength. Laboratory tests with the addition of calcium hydroxide showed constancy of volume up to 48 hours.

In the course of discussion, H. C. Morrison and others stated that calcium hydroxide has little or no water-proofing action, and is especially valuable in absorbing and holding water and preventing too rapid drying out. But it may contain quicklime, which would cause pitting in the concrete. The greater plasticity resulting from its use assists in compacting and increasing the density. The excess of sand used in practice, the addition of water and intercepting of air increases the amount of voids in concrete, and even with use of calcium hydroxide a large proportion of the voids remain unfilled because it is never thoroughly mixed with the dry cement on the work. It does not hinder absorption of water, has no value as a water-proofer, and owing to its retardation of set the forms need to be left on a longer time

BEHAVIOUR OF POZZUOLANIC MORTARS IN SEA WATER.—O. Rebuffat (*Atti. ist. incorrag. Napoli*, 67, 93, 1916). From previous work the author concluded that in sea water pozzuolanic mortars lose almost all their lime and alkali, and the cement finally becomes a hydrated silicate of alumina, which conclusion is confirmed by the work of Giorgis and Cenni on the composition of Roman mortars. The notable quantity of lime present in these mortars is associated with carbon dioxide, and according to Rebuffat this indicates that their reaction with sea water is incomplete and that equilibrium is reached only with complete loss of lime.

PLASTER OF PARIS.—L. A. Keane (*J. Phys. Chem.*, 20, 701, 1916). From results of rough heating experiments with gypsum, and from consideration of various publications on the subject, the author concludes (1) that the liberation of water vapour from gypsum or from plaster of Paris is a slow reaction; (2) that though there is an inversion point at 107° and 971 mm., gypsum may be heated to 200° without being entirely converted into plaster or may lose all

its water by prolonged heating at 110°; (3) plaster may be produced either by prolonged heating at a low temperature (130°), or by a short heating at 200°, but there are no data for determining which plan gives the better plaster; (4) there is no inversion temperature at 128° or at 194°; (5) there is only one modification of anhydrous calcium sulphate, but its properties vary with the method of production; (6) anhydrous calcium sulphate may set very rapidly or more slowly than plaster; (7) calcium sulphate may be hydrated without setting; (8) the properties depend on the degree of agglomeration, and are determined by the temperature and the time of heating; (9) grinding anhydrous calcium sulphate increases its rate of setting, whereas dead-burned plaster with particles of a diameter 0·05 mm. will not set; (10) the volume occupied by crystallised calcium sulphate is much less than the sum of the volume of plaster and water, but a plaster cast is porous and its volume is apparently greater than the sum of the volumes of plaster and water. The filling of the moulds is caused by precipitation of the gypsum in radiating interlocking crystals, but change to a more stable and less dense form may cause further swelling. The setting is retarded by protecting colloids of dissolved substances which decrease the solubility of calcium sulphate. The setting can be accelerated by adding substances, usually electrolytes, which increase the solubility of gypsum.

XII.—ANALYTICAL PROCESSES.

COLORIMETRIC TESTS FOR ORGANIC IMPURITIES IN SANDS.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 327, 1917). Tests based on comparison with standard solutions of alkaline sodium tannate.

ULTIMATE CHEMICAL ANALYSIS OF REFRACTORY MATERIALS.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 671, 1917). Tentative methods. See *Preprint*, TRANS., 16, *Abs.*, 127, 1917.

ROUTINE ANALYSIS OF DRY RED LEAD.—(*Proc. Amer. Soc. for Testing Materials*, 17, Pt. I, 796, 1917). Tentative methods for testing specific gravity, moisture, organic colour, total lead and insoluble matter, lead peroxide and true red lead, zinc, water-soluble, total silica, carbon dioxide, soluble sulphate, and iron oxide.

STANDARD METHODS FOR ROUTINE ANALYSIS OF WHITE PIGMENTS.—(*A.S.T.M. Standards, Amer. Soc. for Testing Materials*, 1917). Includes methods for very small amounts of iron in lead pigments and in leadless pigments, general method for basic carbonate of lead, basic sulphate of lead, zinc-lead and leaded-zincs ((Ozlo White), zinc oxide, lithopone and other similar zinc pigments, whiting and similar calcium pigments, gypsum and plaster of Paris, barytes ("blanc fixe"), silica, china clay and asbestine.

ANALYSIS OF REFRACTORIES.—(*Amer. Soc. for Testing Materials, Preprint of Report of Committee C-8 on Refractories*, 1918). Proposed revisions in Tentative Methods for ultimate chemical analysis. (See TRANS., 16, *Abs.*, 127, 1917.)

As regards *moisture* determination, add "If preferred the sample may be dried in a weighing bottle, from which the required samples shall be weighed out." As regards checking the strength of *potassium permanganate* solution, the ordinary chemical iron wire is not pure enough. If preferred the solution may be standardized against pure sodium oxalate.

With reference to silica, after evaporation to dryness of the first filtrate, the residue is to be taken up with a little HCl and water, transferred to a new filter paper and washed as before, then both silica precipitates transferred to platinum crucible. To residue in crucible (after igniting and weighing) add water and H_2SO_4 once only, and proceed (without evaporating first) to add the HF.

Scientific Paper No. 286 of the U.S. Bureau of Standards by Dr. Blum on "Determination of Alumina as Oxide" is to be referred to in connection with determination of alumina. The NH_4OH used for precipitating alumina must be free from CO_2. The treatment of the ignited alumina precipitate with HNO_3 may be omitted.

In the determination of titania the hydrogen peroxide used should be free from fluorine.

The $Mg_2P_2O_7$ obtained in the determination of magnesia is never pure, but in the analysis of refractories this error is negligible.

ESTIMATION OF POTASH IN SILICEOUS ROCKS.—B. Blount (*The Analyst*, April, 1918). In practice the author has found that treatment with HF and sulphuric acid is by far the most accurate and satisfactory method. Of the very finely ground dried substance ½ to 2 gms. is digested in a platinum crucible for 2 or 3 hours with 10 c.c. purest HF and 2 c.c. sulphuric acid. If necessary, a further 10 c.c. of HF is added, and the whole gently evaporated till most of the sulphuric acid has been fumed off. The anhydrous sulphates are taken up by digesting with HCl, and the diluted solution filtered off through a small filter, leaving the insoluble matter in the dish. This is further digested with HCl and filtered off, and if there is any residue, which is usually due to insufficient attack, it is washed on to the filter paper, which is then well washed, dried, very gently ignited in a platinum crucible, and the process of treatment with HF, etc., repeated. In the case of limestone and other materials the bulk of which can be readily dissolved, the material is first digested with HCl, the insoluble portion being then treated as above and added to the main solution.

The iron, alumina, and manganese are removed by the addition of bromine and ammonia, and a short digestion, the precipitate being filtered off and well washed. Ammonia is added to the filtrate and the whole boiled. Ammonium oxalate is then added and the whole boiled up again. After settling, the calcium oxalate is filtered off and washed well, and the filtrate gently evaporated to a low bulk. The basin is then covered and enough nitric acid is added to destroy the ammonium salts, and, whilst still covered, the whole is evaporated till just dry, or till fumes of sulphuric acid appear. After cooling, the residue is taken up in 2 or 3 c.c. of HCl and a little water, and gently evaporated to low bulk. The solution is diluted, a small excess of clear barium hydrate solution is added, and the whole digested for about half-an-hour, when a slight skin of barium carbonate forms on the top. The precipitate is filtered off and well washed, the filtrate is digested with excess of ammonium carbonate, and the precipitated barium carbonate filtered off and washed. The filtrate is evaporated to low bulk on a water-bath, a few c.c. of HCl cautiously added, the whole then transferred to a small platinum dish and evaporated to dryness on a water-bath. The residue is then very gently ignited over an argand burner to drive off all ammonium chloride, the crude alkali chlorides dissolved in a small quantity of water, a drop or two of ammonium carbonate added, and digested for a minute or two, and the whole filtered off through a very small filter with thorough washing into a weighed platinum dish. The filtrate is evaporated on a water-bath and the residue carefully ignited over an argand, cooled in a desiccator, and weighed, giving the weight of pure alkali chlorides.

For separation of potassium from sodium, the platinic chloride method still seems the most accurate. The pure alkali chlorides are dissolved in a little water and a slight excess of platinic chloride added. The solution is evaporated on a water-bath till it begins to get pasty, then cooled, diluted with enough 80 per cent. alcohol to take up all the sodium salt, and left to stand a few hours. If the quantity of alkali is large, it is better to take up the pasty chlorides in a small measured quantity of hot water, cool, and add absolute alcohol to make the solution 80 per cent. by volume.

The precipitate of potassium platinic chloride is filtered off, washed with 80 per cent. alcohol till quite free from sodium salts, warmed to drive off the

alcohol, and then dissolved through into a weighed platinum dish by means of boiling water, evaporated to dryness dried in an air oven, cooled and weighed.

Platinum residues should be preserved for treatment to recover the platinum.

The best alternative method for separating potassium from sodium is the perchlorate method, a description of which is given from Mellor's "Quantitative Inorganic Analysis."

Dissolve the mixed chlorides in 10 to 15 c.c. of hot water, and then add about 6 times the weight (in grammes) of the mixed chlorides in c.c. of 30 per cent. perchloric acid solution (or the equivalent of any other strength of the acid). Evaporate the mixture on a water-bath to a syrupy liquid until the fumes of perchloric acid begin to appear, then cool a little. Take up the mass with hot water, and add 5 to 6 c.c. of perchloric acid. Evaporate until fumes of perchloric acid begin to appear. Cool and stir with about 20 c.c. of 96 or 97 per cent. alcohol containing 0·2 per cent. by weight of perchloric acid. Keep the potassium perchlorate as coarsely granular as possible. Allow to settle, and decant through a dried and weighed Gooch crucible. Wash residue by decantation through the Gooch crucible three times (about 20 c.c. alcohol necessary for the washing). Transfer the precipitate to the Gooch crucible by means of alcohol. Instead of alcohol a mixture equal parts of 97 per cent. alcohol and ether—20 c.c. in all—is preferred by some for washing the residue. Dry the precipitate at 120° to 130° for about half-an-hour, and then weigh as $KClO_4$.

The specific gravity of perchloric acid of about 60 per cent., 30 per cent., and 20 per cent. respectively is 1·54, 1·20, and 1·12.

XIII.—INSTITUTES, EDUCATIONAL, HISTORICAL.

ORIGIN AND MEANING OF THE TERM CERAMIC.—J. W. Mellor (Trans., 16, 69, 1917). A brief review of the derivation and application of the word.

THE NECESSITY OF SCIENCE AND ART IN MODERN POTTERY MANUFACTURE.—J. Eyre (Trans., 16, 158, 1917). A plea for the more extensive employment of trained scientific men and artists, in the interests of manufacturers themselves and the country generally.

THE ENCOURAGEMENT OF ART IN THE POTTERIES.—A. E. Gray (Trans., 17, 159, 1918). A plea for more artistic decoration of the cheaper wares.

DEVELOPMENT OF CERAMIC DECORATIVE PROCESSES.—F. H. Rhead (*Trans. Amer. Cer. Soc.*, 19, 448, 1917). A brief review of the processes and styles of decoration, with a plea for the recognition of the artistic possibilities in pottery, especially with the co-operation of artists.

CANADIAN DESIGNS.—H. J. Smith (Reprint from "*Industrial Canada*," September, 1917). An article of ceramic and archæological interest, referring to native prehistoric pots and their bearing on distinctive designs. Several illustrations are given.

THE ARTISTIC EXPANSION OF ARCHITECTURAL CLAY PRODUCTS. Leon V. Solon (*The Architectural Forum*, 27, 77, 1917). An article discussing the need of collaboration between clayworkers and architects. Fired and glazed clay is the only satisfactory medium for the use of polychrome in architecture But unlike most other crafts, the potter's art is a sealed book to the layman, and outsiders accordingly often made unfeasible suggestions.

Hence new decorative effects, revivals of useful classic methods, and greater facilities for the use of polychrome, must be developed by the industry itself, along lines indicated by the architect. Many prominent architects (like most sculptors) are deficient in the colour sense, without their ordinary professional work being materially depreciated. Even when the case is otherwise, the means at their disposal are defective. The unsatisfactory position as regards colour is due to the fact that the ceramic palette is at present composed of an accumulation of unrelated trials, produced without any idea that a palette should exist as a complete unit, comprising positive colours, foils, and blending tints—all related, and created to fulfil definite scenic requirements.

The ceramic colour-maker has devoted his main effort to producing positive tints of the maximum purity, oblivious of the fact that in decoration, generally speaking, these colours can only be used with success as accents to those quieter and more neutral tones which will always prevail. The ceramic palette should have for its main divisions the positive, composite, and neutral. Each colour according to its intensity should be represented by from two- to four-tone values, as it often happens that though the preliminary assembly of colours promises well, on its application to the detail the decorative balance is upset by certain items becoming excessively or insufficiently prominent; a change of tone value in the disturbing colour will rectify this. Environment and the relative proportion of areas exert a very pronounced influence on the apparent strength of tints. For the guidance of architects the producer might well establish standardized colour harmonies, reproduced by colour-process ready for filing, showing coloured sections of friezes, mouldings, caps, etc.; these should cover a sufficient variation of design to give him latitude to choose the type, harmony, and colour balance most nearly related to his scheme. By this means any architect unskilled in the use of colour might find a safe foundation from which to start.

An analysis of colour harmonies identified with many historic types of ceramic art points to the conclusion that the establishment of colour systems must have been a common practice in the past.

The majority of the palettes of ancient polychrome pottery, though limited in range, were well balanced, and did not in any way represent the total of technical achievement of their day. In each the decorative aims of the period were so well anticipated that painters could produce eminently satisfactory results almost by formula. The prompt establishment of corresponding facilities by the faïence industry to-day appears to be one of its most urgent needs.

Technical excellence alone is no longer an assured channel of commercial prosperity in lines other than staples. In the clay industry of recent years a somewhat malignant influence has asserted itself, placing a premium on methods adjudged bad by every established ceramic standard. This started as an echo of the English Arts and Crafts movement, organised as a protest against the elimination of the mark of handicraft by mechanical systems; but, misunderstanding the original aims, the "primitive" was affected at the complete sacrifice of all real craftmanship, so far as tile was concerned. These clumsy attempts were heartily welcomed by many architects who, being compelled for certain purposes to use tile in a *milieu* comprising objects that emphasized the peculiar character and beauty of different materials, found in these tiles an expression of plasticity and a texture which had been carefully obliterated from the commercial product. The only alternative previous to the vogue for this type of treatment was the regular commercial tile, the decoration of which was evolved in factory draughting room insulated from every artistic influence; the technical perfection of this article made its decorative shortcomings all the more inexcusable.

Some such extreme may soon invade the terra-cotta and faïence field with disastrous results to industrial standards, unless new decorative horizons be revealed, stimulating the imaginative energy of the architect and proving that this art does not depend on the mishandling of clay to invest it with interest.

The use of polychrome in terra-cotta so far appears to have but two methods of application, the colouring of reliefs and the insertion of the coloured unit. With every tradition of the potter's history of infinite artistic variety and individual beauty, its producers now aim at imitations of another material.

The imitation of stone is in itself an interesting technical achievement, but does not stimulate the imagination to any architectural development of which clay alone is capable. An architect is more likely to develop in his design the pecularities of the substance imitated, than to evolve forms characteristic of the actual material, particularly when the technique is as remote as in the case of granite and clay.

The simple method of sgraffito is suggested as being capable of opening a vast field to the architectural designer, already predisposed to the process by the vogue accorded to the cement sgraffito. It would be applicable to friezes, pilasters, tympanums, panels, decorated column shafts, soffits, etc., giving an effect of rare quality at a comparatively low cost, and having the great advantage of pliability to ornamental variation.

Polychrome features could be developed in this process by the use of multi-coloured slips on the natural coloured ground, and when finished with a semi-transparent matt glaze great delicacy and architectural value could be easily realized.

A very individual architectural embellishment of much delicacy and precision might also be created on the principle applied by the makers of the rare faïence of Oiron, who may have got their ideas from the decoration of contemporary leather bookbindings.

Another direction would be the affixing of ornament in coloured clay to a ground, and this would be specially adapted for interior ceramic decoration.

Review.

Manuel Pratique de L'Emaillage sur Métaux,

(Par Louis-Élie Millenet. Paris, 1917).

The author of this little book on enamelling on metals is a descendant of an old Geneva family, the representatives of which have for several generations been closely associated with the art, and he is himself an artist and enameller. As might be expected in such circumstances, the volume presents (as indeed the title indicates) an essentially practical treatment of the subject in its various branches. There are 25 illustrations, collected on 5 plates.

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